Learning to Drive: From Hazard Detection to Hazard Handling

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Declaration of Originality

This thesis is my own work and has not been submitted for another degree, either at University College Cork or elsewhere.

Ruth Madigan

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Abstract

Hazard perception has been suggested as the most likely source of any skill gap between novice and experienced drivers, as it has been found to correlate with crash involvement across a number of studies. The most commonly used method for measuring hazard perception involves the presentation of video clips showing potentially dangerous events, in which the driver is asked to press a button when they see a hazard. It has been shown that experienced drivers are faster than novice drivers in reacting to the hazards presented in this manner. However, this method lacks ecological validity and it is not clear how performance on this type of test predicts drivers' actual behaviour. The focus in the first two studies of this thesis was on the development of driving simulator studies in which novice and experienced drivers' hazard reaction performance on a hazard detection test is compared with their behaviour in a more dynamic driving environment, requiring hazard handling. Novice (<2 years driving experience) and experienced drivers (>5 years driving experience) completed a hazard detection test which involved watching a simulated drive in UCC's driving simulator and sounding the horn every time a potential hazard was perceived. In order to assess whether discernible changes occurred in actual driving behaviour when encountering these hazards, the groups also completed a hazard handling test whereby they drove the same route in the driving simulator. Results indicated that the hazard handling test was more successful than the hazard detection test in identifying experience-related differences in response time to hazards. This suggests that traditional hazard perception tests may be understating experience-related differences when drivers actually are in control of their vehicle. Results also show that there was a strong relationship between performance on a driver theory test and scores on the hazard detection test. This relationship did not emerge for the hazard handling test, implying that driver theory tests and traditional hazard perception tests may be focusing more on declarative knowledge of driving than on the procedural knowledge required to successfully avoid hazards while driving.

Few driving accidents happen during supervised learner driving. However, one in five Irish drivers crash within a year of passing their driving test, suggesting that the current driver training system does not leave novice drivers fully prepared for the

dangers encountered once they pass their driving test. The third and fourth studies in this thesis aim to address this issue through the development of two types of training regime. These studies focus on the impact of training on driver's reactions to hazards from pre- to post-training simulator tests. In the third study participants were given intensive training on the molar elements of driving i.e. speed and distance judgement and production. This training took place in a test-track-like virtual environment, containing no contextual cues. The fourth study focused on training situation awareness skills, as this concept has previously been linked to hazard perception. Participants were given intense training designed to improve their perception, comprehension, and prediction skills with particular focus on pedestrian, car emerging and traffic light events. The training took place in a simulated urban driving environment. For both studies, summary feedback of performance was provided at the end of each training session. Results from the training studies indicated significant improvement in aspects of speed, distance and situation awareness across training days. However, neither training programme led to significant improvements in hazard handling performance, suggesting that although the training can improve performance in the specific training contexts, it does not necessarily lead to transfer of learning to situations not previously encountered.

1 Literature Review: Introduction to hazard perception within the driving context

The number of traffic crashes has decreased over the last decade, both in Ireland, and across Europe and the USA (NHTSA, 2006; OECD, 2006; RSA, 2011). In spite of this reduction, traffic accidents are the second most common cause of death for people aged 15-29 years, and the greatest cause for men in the same age group (OECD, 2006). Poor hazard perception and hazard handling have been identified as some of the main causes of these traffic accidents (Chan, Pradhan, Pollatsek, Knodler, & Fisher, 2010; Velichkovsky, Rothert, Kopf, Dornhöfer, & Joos, 2002). In fact, according to Horswill and McKenna (2004), hazard perception is one of the few aspects of driving skill that has been reliably correlated with crash risk. The aim of this literature review is, therefore, to provide a synopsis of the research on hazard perception, particularly in relation to young, novice drivers, with the aim of identifying how these important hazard perception skills can be improved, along with what direction future research in this area should take.

1.1 Accidents Involvement of Young/Inexperienced Drivers

In the United States alone, more than 40,000 people die in motor vehicle crashes each year, making it the most common cause of death for those between 4 and 35 years of age. However, driving safety has improved substantially over the past 50 years, with fatalities in the United States dropping from 7.24 per million miles travelled in 1920 to 1.53 in 2000 (see Lee, 2008). In Ireland the number of annual road deaths has dropped from a peak of 640 in 1972 to 186 in 2011 (RSA, 2009, 2012). There are many reasons for this, including improved road infrastructure; the development of passive safety systems such as airbags, and campaigns which target issues such as speeding, alcohol use and seat belt use (Lee, 2008; OECD, 2006). However, there is still a long way to go, and death rates for 18-24 year old drivers remain more than double those of older drivers (OECD, 2006).

1.1.1 Age and Accident Risk

Statistics from around the world provide evidence that young, novice drivers are the group most likely to be involved in a traffic accident. The fatal crash rate per mile driven for 16-19 year olds in the U.S. is nearly three times the rate for drivers aged 20 and over (Safety, 2011). In the state of New South Wales in Australia, young drivers aged 17-25 years account for 29% of total fatalities and injuries due to car crashes, whereas, young people in this age group comprise only 13% of the population (Australian Bureau of Statistics, 1998; cited in Lam, 2003). In Ireland the situation is no different, with 30% of those who died on the roads in 2011 being less than 25 years old, despite this group accounting for only 12% of the total population (RSA, 2011).

1.1.2 Experience and Accident Risk

Driving experience is most frequently measured using time elapsed since licensure (McCartt et al., 2003); although this is confounded with age, as more experienced drivers tend to be more mature. Attempts have been made to define experience as the distance in miles/kilometres driven since the test pass date, but this is difficult to determine, and may also lead to an exposure effect as the driver may be more experienced as a result of having driven a greater distance, but the greater the distance travelled, the more likely it is that they will have had an accident (Clarke, Ward, Bartle, & Truman, 2006). Research with teenage drivers in the U.S. has found that the crash rate per month of licensure, adjusted for miles driven, fell from 2.3 crashes per 10,000 miles driven during the first month to 1.1 crashes during the second month and then generally continued to decline (McCartt, Shabanova, & Leaf, 2003). Their data suggests that a principal source of the very high crash risk for 16- and 17-year old beginning drivers is their lack of driving experience rather than their age.

Interestingly, the greatest crash risk may actually be after drivers have passed their initial driving test. In the UK, twenty per cent of newly qualified drivers in the UK have an accident in their first year of driving, with the highest accident rate occurring in the first six months after passing test and reducing steadily for the first three years (Wells, Tong, Sexton, Grayson, & Jones, 2008). These findings have also been replicated in Australia, Canada, Sweden, the Netherlands, and the USA (see Hutchins, 2008). Mayhew, Simpson, and Pak (2003) found that the monthly crash rates for a sample of learner drivers in Nova Scotia were substantially lower than those of novice drivers who had obtained their full driving permit. Maycock, Lockwood, and Lester (1991) showed that while the likelihood of an accident dropped 6% between the ages of 17 and 18, it fell an average of 30% after the first year of driving at any age. Forsyth, Maycock, and Sexton (1995) found that the effect of experience alone for young drivers over the first three years of driving was about four times that of age. They found that a 40% reduction in accident liability between the first and second years of driving for 17-18 year olds could be attributed to experience. Although the difference was more pronounced for the youngest drivers, the effects of experience were apparent at all ages.

The research above shows that accident rates vary with both experience and age (McKnight & McKnight, 2003). Although the driving attitudes and beliefs of younger drivers can account for some of the accidents, it has been demonstrated that driving experience can have a significant effect on crash risk even when the effects of age are taken out. As older drivers are generally more experienced than younger drivers, there is a natural confound between age and driving experience making it difficult to separate out their individual effects (Groeger, 2006). However, the fact that experience level does appear to make an independent contribution to accident risk is very important for driving research, as maturity cannot be taught, but it may be possible to increase experience more rapidly (Grayson & Sexton, 2002). In terms of age-related factors, it could be argued that young drivers overrepresentation in road accidents reflects the fact that teenagers are more willing to take risks (e.g. Lam, 2003). However, others would argue that a big part of the problem is that young novice drivers' performance is inferior in several ways to that of experienced drivers. They lack sufficient hazard perception, attentional control and calibration skills to successfully negotiate dangerous driving events (Deery, 1999; Groeger, 2000; McCartt et al., 2003; McKnight & McKnight, 2003). This distinction is sometimes referred to as the difference between driving style (or behaviour) and driving skill (or performance). The dramatic risk reduction which takes place during the first few months after licensure suggests that there is an improvement in driving skill which cannot be linked to changes in motivation or style (Sagberg & Bjørnskau, 2006). While it has been acknowledged that attitudes play a role in the relatively high accident liability of young novice drivers, studies have shown that when attitudes are partialled out, skill deficits remain (Gregersen & Bjurulf, 1996).

1.1.3 Experience and Hazard Perception Skill

Research suggests that novice drivers detect hazards less holistically, less quickly, and less efficiently than their experienced counterparts (Deery, 1999). Hazard perception skill has been suggested as the most likely source of any skill gap between novice and experienced drivers, since it is the only domain-specific skill that has been found to correlate with drivers' accident records across a number of studies (Horswill & McKenna, 2004). For that reason, the focus in this thesis will be on the development of a measure of hazard perception, along with the development of a training programme to improve novice drivers' competence in this area.

1.2 History and Definition of Hazard Perception

Hazard perception is the only driving-specific skill that has been found to correlate with crash involvement, thus making it a very important area of driving safety research (Grayson & Sexton, 2002; Horswill & McKenna, 2004). Studies have shown that various hazard perception tests can distinguish between novice and experienced drivers, and crash involved and non-crash involved drivers (Horswill & McKenna, 2004).

Hazard perception as a concept has been around for over 40 years. As far back as 1969, Currie looked at participant's speed of response in identifying potential collisions in model cars. He found that accident-involved participants responded to potential collisions more slowly than did accident free drivers, although the groups did not differ in simple reaction time. In the 1970's and 80's, researchers looked at various different aspects of hazard perception including hazard identification and rating (Armsby, Boyle, & Wright, 1989; Finn & Bragg, 1986; Soliday, 1974); the measurement of visual patterns (Mourant & Rockwell, 1972); and hazard detection and response time (Pelz & Krupat, 1974; Quimby & Watts, 1981).

Although there has been much investigation into hazard perception as an element of driving skill, there seems to have been little attempt to provide an exact definition of the concept and researchers tend to define the term somewhat loosely (Jackson, Chapman, & Crundall, 2009). McKenna and colleagues have defined hazard perception as "the ability to read the road and anticipate forthcoming events" (McKenna, Horswill, & Alexander, 2006, p. 2). Deery (1999), in his literature review, describes it as “the process of identifying hazardous objects and events and quantifying their dangerous potential” (p.226). Crundall et al. (2012) refer to hazard perception as “the process of detecting, evaluating and responding to dangerous events on the road that have a high likelihood of leading to a collision” (p.600). However, all of these definitions require a further explanation of what constitutes a hazard or a dangerous traffic situation, and this information is rarely supplied by researchers (Jackson et al., 2009).

Although no one accepted definition of hazard perception exists, at a practical level the concept seems to be recognised as involving “appreciation, anticipation, and reading the road”(Grayson & Sexton, 2002, p.4). Smith, Horswill, Chambers, and Wetton (2009) claim that hazard perception is a multi-component cognitive skill which requires the scanning of the road environment, fixation on appropriate stimuli, and a ‘holistic’ interpretation of the salience of hazards (p.729). Similarly Isler, Starkey and Williamson (2009) describe “good hazard perception skills” which are claimed to result “in a holistic assessment of risk, which combines information from multiple sources 360° around the car. This allows drivers to anticipate and predict traffic constellations in the near future which will then enable them to plan appropriate courses of action” (p.445). However, there is no evidence of how or if this ‘planning’ occurs.

The majority of definitions seem to focus on the process of anticipating a hazard, without taking into account what happens once a hazard is identified. For the purposes of the research in this thesis, hazard perception will be defined as “the ability to quickly perceive and respond to a potentially dangerous driving event” (Crundall, Chapman, Phelps, & Underwood, 2003, p. 164), as it incorporates both the process of detecting a hazard and responding to it, although it provides no explanation for how the response is selected or implemented.

1.3 Theoretical Frameworks surrounding Hazard Perception

Unfortunately, to date, very few studies have provided a theoretical framework for their understanding of hazard perception. This may offer some explanation for the number of different definitions of hazard perception that abound. Without a theoretical understanding of the concept, it is difficult to explain what exactly we would expect hazard perception to entail, what exactly constitutes a hazard, and which particular hazards contribute most to crash risk. The current section will outline three of the relevant theoretical models that have been provided to aid our understanding of hazard perception skill.

1.3.1 Situation Awareness

McKenna and colleagues have defined hazard perception as “the ability to read the road and anticipate forthcoming events” (McKenna et al., 2006, p. 2). This definition is closely linked to the concept of situational awareness developed by Endsley (1995a) which suggests that drivers need to perceive the elements in the environment, comprehend the meaning of these elements and project the status of these elements into the future.

Endsley (1995a) defined situation awareness (SA) as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p. 36). According to this definition SA has a hierarchical structure, to which there are three stages. Level one SA involves the perception of environmental elements and deals with the present. Perception involves the processes of monitoring objects, events, people, systems and environmental factors; along with the maintenance of vigilance over their current states, locations, conditions, modes, and actions. Level two SA involves the comprehension of this information. It goes beyond simple awareness of the elements that are present to include an understanding of those elements. This understanding will be based on the person’s current goals and requirements. For example, a time-pressured driver will interpret stimuli differently to a “Sunday” driver enjoying their trip (Haworth, Symmons, & Kowadlo, 2000). The third level of SA is known as projection, and provides the foundation for effective decision making. It requires the ability to project the future actions of elements in the environment, at least in the near term. It can only be achieved through knowledge of the dynamics of a given situation (perception) and an understanding of what those elements mean (comprehension).

As all three levels of SA require aspects of working memory and attention, cognitive load can be high during SA. However, according to Endsley (1995a) experts will develop mental models or schemata around a system which will enable SA performance to become more automatic. She refers to mental models as "mechanisms whereby humans are able to generate descriptions of system purpose and form explanations of system functioning and observed system states, and predictions of future states" (p.43). By linking information about the current state of the system to schemata in memory, a mechanism for single-step, recognition-primed decision making is formed. When an individual has a well-developed mental model of a particular system, the model will provide for the direction of attention to critical and salient cues; the development of expectations regarding future states of the environment based on the projection mechanisms of the model; and a direct single-step link between recognised situation classifications and previously encountered actions. This will improve as experience with a system increases (Endsley, 1995a). When cues trigger automatic responses from long term memory, working memory can be kept free of processing load, shortening the reaction time to these cues. This is not a completely automatic or unconscious process. It is likely that the individual will be conscious of the situational elements that triggered the automatic retrieval of information from memory (SA), but may not be conscious of the mechanisms used in arriving at the resultant action selection. Thus, SA itself is not an automatic process, but may lead to automatic selection of response. To give an example from a driving context, an individual needs to acquire sufficient vehicle handling skills so that they can swerve/brake to avoid an obstacle on the road and avoid colliding with other traffic. Without these learned motor skills, the driver will not have an automatic response ready when they see an unexpected hazard e.g. a child running onto the road in front of them; and thus, may not be able to deal with the hazard even when they perceive it (Haworth et al., 2000). Therefore, adequate SA skills are a pre-requisite for good performance but do not explain the whole process of this performance. When cues trigger automatic responses from long term memory, working memory can be kept free of processing load, shortening the reaction time for learned responses (Endsley, 1995a).

The concepts of situation awareness and hazard perception have been linked by a number of researchers (Horswill & McKenna, 2004; Jackson et al., 2009; McGowan & Banbury, 2004), although no clear conceptual framework exists. Underwood, Crundall, and Chapman (2011) define hazard perception as the driver's situation awareness for a dangerous configuration of roadway and road users. They claim that drivers with good hazard perception skills would have awareness at the third level of Endsley's (1995a) model, and would be able to anticipate changes in the traffic environment. McGowan and Banbury (2004) go so far as to argue that hazard anticipation is a function of SA, and is actually synonymous with the projection level of SA. Their study found a strong positive correlation between a measure of situation awareness and a traditional hazard perception measure, providing support for the idea that they both tap into the same underlying skill. However, as our previously stated definition of hazard perception refers to both perceiving and responding, situation awareness does not provide enough information to adequately describe all aspects of hazard perception. There is no information on what happens after a hazard is adequately perceived, understood, and its potential future state evaluated. It does not provide any explanation for the hazard response selection process. Thus, it can be argued that situation awareness is a prerequisite for good hazard perception, but does not provide a model for all aspects of the process.

1.3.2 Task Capability Interface Model

In his Task Capability Interface Model (TCI), Fuller (2000) claims that as task difficulty increases (above a minimum level), so does the experience of risk. The TCI model argues that what is important while driving is not risk but task difficulty. Drivers respond to variations in task difficulty rather than feelings of risk, and they respond to these variations both in terms of autonomic arousal and adjustments in speed. Task difficulty can be broken into two processes: task demand and driver capability (see Figure 1).

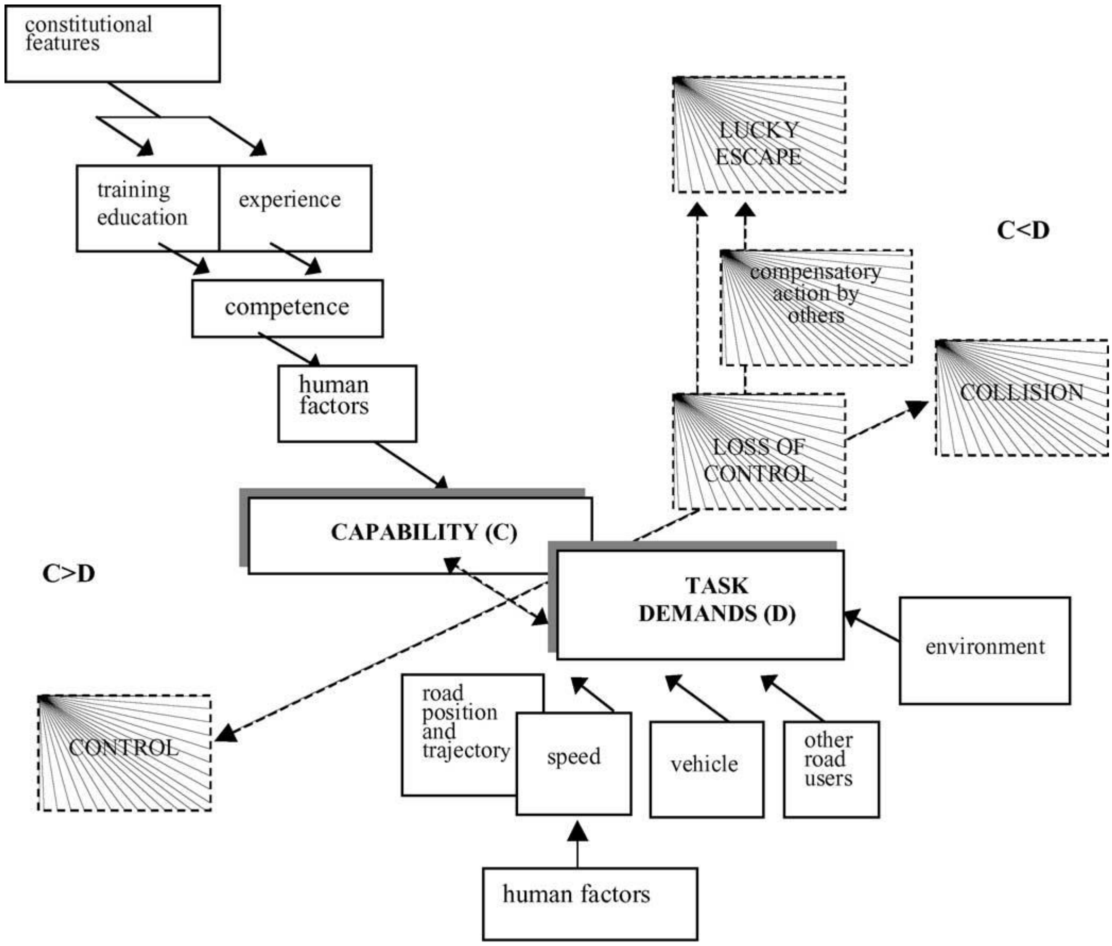


Figure 1: Task Capability Interface Model (from Fuller, 2005)

Task demand is the objective complexity of the task. This is determined by a combination of environmental features (e.g. visibility, road alignment, road marking, curve radii), the behaviour or other road users, control and performance characteristics of the vehicle (e.g. information displays), and driver control aspects (e.g. speed, vehicle trajectory). At any moment in time these features combine dynamically to determine the task of the driver as they attempt to make safe progress towards the goal of the journey. Speed is seen as one of the most important contributory factors to task demand as the faster a driver travels, the less time they have available to gain information about the environment, process it, and respond to it (Fuller, 2005).

Driver capability refers to the momentary ability of the driver to deliver his or her level of competence i.e. what the driver is actually able to do at any given moment (Fuller, 2000). Competence sets an upper limit on capability, but that capability may be further challenged by human factors variables which include aspects such as fatigue, drowsiness, emotion, alcohol and other drugs, stress, distraction and level of motivation. Competence is determined in part by the mental and physical characteristics of the individual (e.g. perceptual acuity, coordination, impulsiveness) but will also emerge from processes of training, formal learning and experience. It has three basic levels, a skill-based level, a rule-based level and a knowledge based level. Novice drivers must rely on their knowledge based learning (i.e. general knowledge of the world) much more than experienced drivers, as they have not yet mastered the skill based level (i.e. unconscious, integrated and smooth driving control, requiring little working memory capacity) or rule based levels (i.e. if-then relationships). This accounts for both their slower reactions and their higher proportions of wrong solutions (Fuller, 2000).

Driving task difficulty emerges out of the transaction between the level of capability and the demands of the task (Fuller, 2000). Where capability exceeds task demand, the task is easy; where capability equals demand the driver is operating at the limits of their capability and the task is very difficult. Where demand exceeds capability, then the task is too difficult for the driver to manage and they fail at the task. This can result in a loss of control, perhaps leading to a collision or the vehicle going off-road. Thus, in essence, task difficulty is inversely proportional to the difference between task demand and driver capability (Fuller, 2005). Most of the time drivers are able to manage this interface to maintain control and achieve a safe outcome, either by modifying task demand or by altering their capability. However, sometimes unexpected changes in task demand occur e.g. a child running out on to the road. The impact on safety of an unexpected increase in task demand will be more significant the closer the driver is to the critical threshold (Fuller, 2000). Experienced drivers are more likely to make use of anticipatory responding, or reading the roadway ahead of them. This type of responding is advantageous if the driver makes an error or mistake, as they will still have the possibility of error correction. However, if the driver is in reactive mode, as many novice drivers will be, opportunities for error correction will be relatively limited (Fuller, 2005).

The TCI is useful in that it takes into account aspects of driver behaviour and characteristics, along with the influence of external environmental characteristics. This provides a deeper understanding of the factors which influence drivers' interactions with the environment. However, the model does not go into detail on the specific mechanisms by which drivers deal with increased task demands, and the focus is mainly on the impact of speed in dealing with potentially hazardous events.

1.3.3 A Cognitive Account of Driver Behaviour

In order to provide a theoretical framework for risk responses while driving, Groeger (2000) divided the process of risk response decisions into four hypothetical stages. The first stage is a process that detects changes which would imply some interruption/threat to the currently active goals. The second is a process that appraises the threat of these changes. Thirdly the driver must select and construct the most appropriate form of action to deal with the particular set of circumstances; and finally, the driver must implement any changes in current activity necessary. This model provides a very useful way of thinking about hazard perception as it incorporates the anticipation stages outlined through situation awareness (detecting a change in the environment and appraising the threat), but also incorporates a mechanism for hazard responses (selection and implementation of an appropriate action).

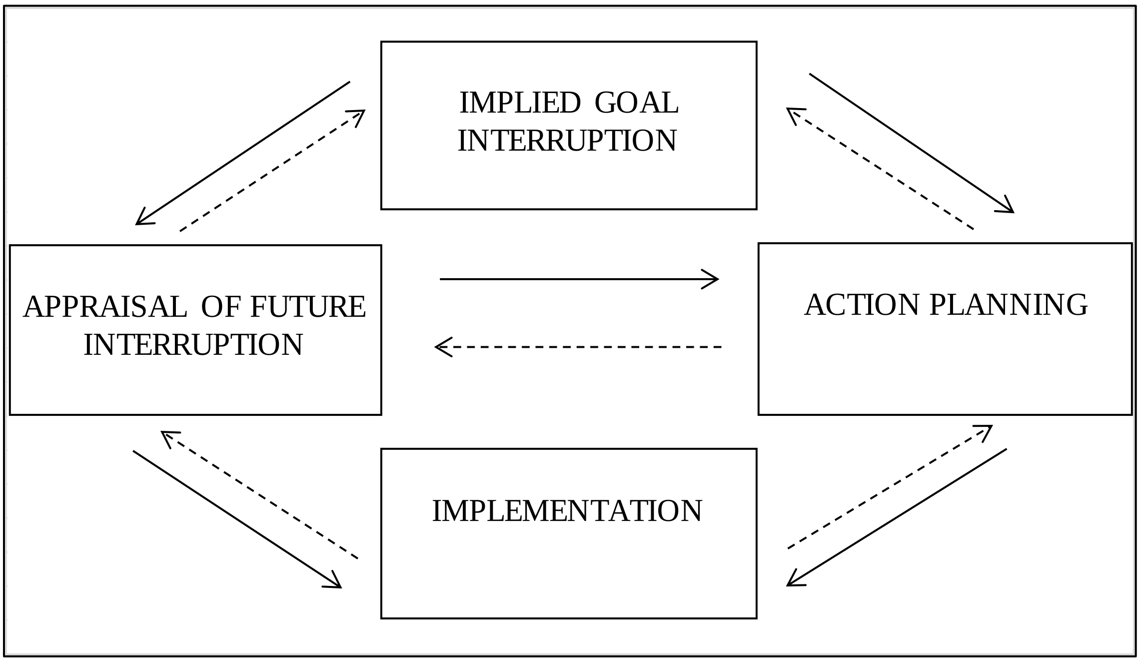


Figure 2: Processes involved in responding to risk (from Groeger, 2000). The bold arrows represent hypothetical forward links. The dashed arrows represent hypothetical feedback links.

Groeger (2000) argues that there are a number of goals which simultaneously influence driving behaviour. Amongst these are achieving the purpose of the journey, maintaining a safe distance from other traffic, arriving at a destination in a timely manner. According to the first stage of the model (implied goal interruption), some discrepancy or discontinuity in the driving environment is detected which is predictive of a goal interruption or being endangered (e.g. no longer maintaining a safe distance from the car ahead). This was originally conceptualised in Groeger's (2000) model as hazard detection, and this is the term that will be used throughout the rest of this thesis. The individual may not be consciously aware of the discrepancy or discontinuity, or be subsequently able to report it e.g. seeing a school bus and preparing to decelerate if necessary should a child appear. Detection of implied goal interruptions is dependent on retrieval from prior experience, and is likely to be better among those with substantial and varied experience of driving. Individuals will also differ in their hazard detection as a result of their perceptual ability and their propensity to evaluate situations as threatening (Grayson, Maycock, Groeger, Hammond, & Field, 2003).

Once detected, the threat implicit in the future interruption of the current goal is evaluated. At this stage beliefs about one's driving ability, the extent of the threat present, the seriousness of the consequences, and the controllability of the threat are all combined to yield some determination to act. Threat appraisal is also influenced by experience, with drivers appraisal of previously encountered, well-learned risks being different to the appraisal of situations not previously encountered.

Action planning/selection occur when drivers have to determine how to achieve a newly established goal, or to identify some action that will prevent some temporary goal interruption. The detection of an upcoming hazard leads to a break in the current control structure, the extent of which depends on the outcome of threat appraisal processes. A threat which is considered to be of little importance will lead to relatively little disturbance to normal control of activity, and may not elicit a response. A threat that is appraised as very important will cause a reallocation of attention and the interruption of current goals. This stage requires a great deal of mental load, as the various options for action are considered. This mental load arises from the requirement to attend to a highly salient/threatening stimulus and still maintain the attentional capacity to perform the selected action. Once again, experienced drivers are more likely to have knowledge of the potential outcomes of various actions, and thus are more likely to be able to select appropriately from among these actions.

The final stage of this model, the implementation stage, refers to the way in which a selected action is performed, although it also covers situations where the decision is to maintain current activity i.e. change nothing. Adequate implementation requires the rapid and correct sequencing of basic vehicle handling skills.

The model allows for all of the processes involved to occur almost simultaneously. It also allows for feedback between the various stages. For inexperienced drivers feedback from implementation to action selection stages about outcomes is invaluable in improving action selection. Successful and unsuccessful implementation can also feed back into threat appraisal by increasing or decreasing the driver’s self-assessments of their skill. If drivers were given the opportunity to practice the implementation of the kinds of action available to action selection under supervision, then this might be valuable for decision making in action selection as well as increasing the chances of successful implementations in the future (Grayson et al., 2003; Groeger, 2000).

The major strength of Groeger’s (2000) model in explaining hazard perception skill is the inclusion of the action selection and implementation stages. Its use of the appraisal is also a means of incorporating emotion and personality characteristics into the process of hazard responding. This allows us to examine both the anticipation skill required to detect and understand a hazardous event in the environment, and the vehicle handling skills necessary to adequately respond to that hazardous event. The presence of a feedback loop also enables us to better understand the manner in which novice drivers learn and can improve their hazard perception skill. The model will be used to frame the discussion of hazard perception testing and training in Chapters 3, 4 and 5 of this thesis.

1.4 Measuring Hazard Perception

The most commonly used methodology for measuring hazard perception is to focus on the perception-reaction time to perceived hazard (Borowsky, Oron-Gilad, & Parmet, 2009; Horswill et al., 2009). In tests using this methodology, drivers are asked to observe traffic-scene movies or pictures and to press a response button as soon as they detect a hazard (e.g. Chapman & Underwood, 1998; Sagberg & Bjørnskau, 2006; Wallis & Horswill, 2007). However, some researchers have questioned the validity of using response time alone to measure drivers' hazard perception abilities (see Groeger, 2000; Jackson et al., 2009), and as a result studies have examined other aspects of hazard perception such as visual fixation patterns (e.g. Chan et al., 2010; Crundall et al., 2003; Velichkovsky et al., 2002); hazard classification (Borowsky et al., 2009); hazard location identification (Fisher et al., 2002; Smith et al., 2009; Whelan, Groeger, Senserrick, & Triggs, 2002); and speed choices (Grayson et al., 2003; Wang, Zhang, & Salvendy, 2010). In the majority of the tests described above, participants' reactions were measured in simulated environments, often involving films recorded from the driver's eye position. Although studies have rarely investigated actions taken after the hazards have been detected, it is widely assumed that the additional time available for drivers who respond more quickly confers a safety advantage (Groeger, 2000; Groeger & Chapman, 1996). In the following sections the results arising from studies using these varying methods will be explored.

1.4.1 Novice versus Experienced Drivers

The focus of this thesis is on the hazard perception deficits of young, novice drivers. As outlined in Section 1.1, novice driver's lack of experience has been linked with increased crash risk across numerous studies worldwide. Therefore, experience level has been used as a surrogate measure for safety in much of the research into hazard perception skill (Crundall et al., 2012; Horswill & McKenna, 2004). A number of studies have found differences between novice and experienced drivers response times to hazards presented in a film (see Horswill & McKenna, 2004; Quimby & Watts, 1981; Wallis & Horswill, 2007). It is generally accepted, with a few notable exceptions (Chapman & Underwood, 1998; Crundall et al., 2003; Sagberg & Bjørnskau, 2006), that experienced drivers have faster response times, and more effective scanning patterns than novice drivers in these types of test. Some of the more relevant studies will be discussed in more detail in this section.

1.4.1.1 Eye Movement Patterns

Mourant and Rockwell (1972) were one of the first to look at experience differences in hazard perception skill. They analysed visual search strategies of novice and expert drivers and found that novices concentrated their search on a smaller area than experts, and that they also tended to fixate closer to the vehicle. Crundall et al. (2003) compared the hazard ratings, eye movements, and physiological responses of police drivers with both novices and age-matched control drivers, while viewing video clips of driving taken from police vehicles. Their results showed that novices had longer fixation durations and a greater vertical spread of search than other drivers. Interestingly, Crundall et al.'s (2003) study failed to find any significant differences between novice and experienced drivers rating of the hazardousness of driving scenarios. However, ratings of hazardousness were made using a moving scale, with participants being required to move the position of a slider constantly according to how hazardous they felt the scenario was at any given moment. This may have been difficult for participants to use, and also may have led to delays in deciding what rating to give to a continuously moving event. In addition, hazardous situations had not been previously defined by the experimenters so all aspects of the drive were examined as being potentially hazardous depending on the ratings given.

1.4.1.2 Response Time and Hazard Classification

In a study by Wallis and Horswill (2007), participants completed a traditional hazard perception response time test, whereby they watched a video containing twenty hazardous events and were asked to respond by pressing a button when they anticipated a potential traffic conflict occurring. In addition, they provided a hazard rating of a further twenty-three hazard videos using a 20-point rating scale. Results indicated that experienced drivers (over 10 years' experience) responded significantly faster on the hazard perception test than untrained novice drivers (less than 4 years' experience). However, these differences did not carry over to the hazard rating task. Mean hazard rating was not actually correlated with mean hazard response latency. The fact that there were no group differences in the hazardousness ratings of scenes shows that both groups could successfully identify hazardous situations when rated un-timed and out-of task, but novice drivers were less likely and slower to respond when under time constraints.

Smith et al. (2009) investigated the impact of high and low sleepiness on both novice (average 1.65 years' experience) and experienced drivers (average 14.4 years' experience) using a 20 minute video-based hazard perception test where participants had to click on the location of a hazard on a computer screen. They argue that this method is better than simple response time tests as it gives information on both the reaction time and the accuracy of hazard perception. Experienced drivers displayed significantly faster hazard reaction times and identified more hazards than novice participants, and were also less susceptible to the detrimental effects of sleepiness. It is interesting to note that novice drivers had faster response times than experienced drivers in a simple reaction time test, suggesting that it is a failure in hazard detection skills rather than motor skills that leads to the slower hazard perception reaction times. However, although the researchers in this study could be certain that participants were responding to the correct hazard, there was once again no indication of what type of driving response would be made.

A problem with a lot of hazard perception testing is that performance differences may be reflecting differences in participant's perception of what constitutes a hazard, differences in their hazard perception speed, or differences in their response speed. This may explain why there have been conflicting results in hazard perception-reaction time tests. In order to allow for the influence of processing time in hazard perception, Jackson et al. (2009) used situation awareness theory to produce a different type of hazard perception test. They developed a study whereby novice (average 7 months driving experience) and experienced drivers (average 59 months driving experience) were presented with video clips of actual driving scenarios. The clips were stopped just prior to the onset of a hazard and the screen either went black (cut-to-black) for 20 seconds or the final still image remained (freeze-frame) for 20 seconds. Participants were then asked questions about the source and location of the hazard and what happened next. They were also asked to provide ratings of the hazardousness of the situations. It was found that both experienced and novice drivers provided similar hazardousness ratings in both the freeze frame and cut-to-black conditions; however novice drivers felt significantly less confident in their answers in the cut-to-black condition than in the freeze frame condition. Novice drivers performed significantly worse on questions regarding the hazards in the cut-to-black condition than in the freeze-frame condition; and their performance was significantly worse than experienced drivers in the cut-to-black condition. There were no significant differences between the novice and experienced groups in the freeze-frame condition. Overall, the results indicate that novice drivers were unable to gather information rapidly enough to make predictions about what happens next when placed under a time constraint such as the cut-to-black condition. This suggests that novice deficits in hazard perception may be the result of slower processing rather than less awareness of hazards.

Huestegge, Skottke, Anders, Müsseler, and Debus (2010) compared the eye movements of novice (less than 2 years' experience) and experienced drivers (between 2 and 5 years' experience) in a hazard perception task. Participants were shown static images of traffic scenes, which had been divided by experts into categories of low, medium and high braking affordance. They were asked questions after some of the pictures, and were also instructed to respond as quickly as possible by pressing a button in any scene which they felt required a braking response or speed reduction. Results indicated that overall reaction time was faster for experienced than novice drivers. However, there were no significant differences between the groups in the number of button press responses made, with all drivers making the most responses to scenes with high braking affordance, and the fewest responses to scenes with low braking affordance. When focusing on eye-movements, there was no difference between the two experience groups in terms of time between scene onset and the first fixation on the hazard region, but there was a significant experience effect on the time between first fixation on the hazard region and the button press response. Huestegge et al. (2010) concluded that the experience related differences in response time to hazardous scenes was due to faster processing after the initial fixation on a hazard, since scene scanning times did not differ between the groups. Similar to the Jackson et al. (2009) study, these results suggest that experienced drivers do not differ from novice drivers in terms of knowing where to look in a traffic scene but appear to be faster at making a decision as to whether a fixated object represents a hazard or not. However, there is still a lack of clarity as to where the differences in hazard processing occur. In addition, this study used static images so it is not clear whether or not the findings would replicate in a more ecologically valid driving setting.

1.4.1.3 Specific Hazard Situations

Sagberg and Bjornskau (2006) examined the response times of novice drivers with one, five, and nine months driving experience to that of drivers with over 10 years' experience. Drivers watched a 10 minute video containing naturally occurring traffic hazards and were instructed to press a button as soon as possible whenever they detected a potentially hazardous situation. There was no significant difference between the three novice groups and the experienced group in either the average number of hazard responses made, or the average reaction time to hazards. Although the overall effect of response time did not reach significance, experienced drivers did have significantly faster response times than novices to six individual hazard situations (e.g. a pedestrian unexpectedly taking a step towards the kerb). The authors suggested that there may be particular hazards for which the gap between novice and experience drivers is bigger than others.

Crundall et al. (2012) explored this idea of structural differences between hazards which make them more or less suitable for discriminating between safe (experienced) and unsafe (novice) drivers. They distinguished between three main categories of hazard; behavioural prediction hazards, environmental prediction hazards and dividing and focusing hazards. Behavioural prediction hazards occur where drivers can predict a hazardous situation by identifying a potential hazard and assessing its attitude, position and trajectory (e.g. a pedestrian standing at the side of the road who could walk out in front of the driver); and environmental prediction hazards occur where drivers can identify that the environment through which they are driving may contain a hidden hazard (e.g. a parked truck which may be hiding a pedestrian). Finally, dividing and focusing attention scenarios contain more than one hazard precursor meaning drivers need to monitor both precursors before focusing on the eventual hazard (e.g. a parked bus on one side of the road, and a pedestrian on the other side) (Crundall, Andrews, Van Loon, & Chapman, 2010; Crundall et al., 2012). The experiment used a simulated driving environment to examine the driving and eye-movement behaviour of novice (7.5 months' experience) and experienced participants (16.4 years' experience). Results showed that all hazards were fixated more often by experienced than novice drivers. Learner drivers also took longer than experienced drivers to fixate all hazard types. When the specific hazard types were examined, it appeared that novice drivers were particularly poor at noticing environmental prediction hazards and were likely to miss these altogether (Crundall et al., 2012). This provides support for Sagberg & Bjørnskau's (2006) idea that different hazards may be more/less successful in discriminating between experience groups.

Two recent studies by Scialfa et al. (2012; 2011) provide further evidence for this idea. They used both short video clips of hazards and still images of driving scenes to examine the hazard perception skill of novice (less than 6 months experience) and experienced drivers (more than 2 years' experience). Participants were asked to identify traffic conflicts quickly, and to rate the level of hazard and visual clutter in the scene. Novice drivers had significantly slower composite response times than experienced drivers to the traffic conflicts in both studies. However, a further analysis of the static scenes showed only eight individual scenes (out of 120) where the difference reached statistical significance, once again suggesting that certain hazards may be better at discriminating between experience groups than others. A shortened test, based on the most discriminating scenes, also showed that novice drivers had significantly slower response times to hazards, and a significantly lower hit proportion than experienced drivers. Unlike Wallis and Horswill's (2007) study, experienced drivers also gave significantly higher hazard ratings for all of the scenes included in the shortened still image test, and missed significantly fewer hazardous events in the test using video clips.

Isler et al. (2009) included a hazard perception dual task in their study of hazard perception and training. Participants were required to carry out a central tracking task which involved using a mouse to maintain a moving target dot in a stationary rectangle digitally superimposed in the lower central area of a driving video. At the same time participants were asked to respond to hazards and potential hazards displayed on the screen by clicking on the mouse when a hazard was identified and also giving a verbal description of that hazard. Results indicated that experienced drivers detected and correctly identified a significantly larger percentage of hazards compared to novice drivers, but, at the same time novice drivers made a significantly smaller number of errors in the tracking task than the experienced drivers. This may be an indication that novice drivers have less awareness of where to focus their attention when faced with distractions while driving. This would suggest that they would have difficulty with the threat appraisal process outlined in Groeger's (2000) cognitive model, as they did not assign enough attention to the most threatening task i.e. the driving environment. However, there were a number of issues with the design of this study and thus some caution must be taken when interpreting these results. The experience groups were not clearly defined and unevenly matched (there were only eight experienced drivers). In addition, missing values were replaced with the mean for the response group i.e. novice or experienced group, rather than the overall mean. This may have led to conflated experience differences. Finally, participants were only asked to identify immediate hazards and so any potential hazards may have been ignored. Since a big part of hazard perception is the anticipation of hazards, the test may not have been tapping into hazard perception per se.

1.4.1.4 Summary of Research Findings

The studies comparing novice and experienced drivers have obtained mixed results. It would appear that novice drivers have inferior visual scanning patterns to experienced drivers, particularly in terms of having longer fixation times and a wider vertical spread of search (Crundall et al., 2003). They also seem to have slower response times to hazards on the whole, but this appears to be linked to the type of hazard presented (Sagberg & Bjørnskau, 2006), and it is unclear as to whether this difference arises in terms of a failure to detect hazards, or a failure to correctly assess the threat present. Smith et al. (2009) and Scialfa et al. (2012) found that novice drivers were inferior at rating the hazardousness of given situations. However, the results of Jackson et al.'s (2009), Huestegge et al.'s (2010) and Wallis and Horswill's (2007) studies provide conflicting evidence and suggest that novices' poorer response times to hazards may be more due to a lack of knowledge of what to do once the hazard is detected, than a lack of awareness of what constitutes a hazard. Overall, these results indicate that although there is a lot of evidence that novice drivers do have poorer hazard perception skill than experienced drivers (at least in terms of hazard detection), there is still a lack of understanding of where in the cognitive process these differences in hazard perception lie. By separating the processes of hazard detection and threat appraisal from action selection and implementation, it may be possible to determine where any differences in the processing of hazardous situations occur.

1.4.1.5 Developing Measures of Hazard Perception

Wetton, Hill, and Horswill (2011) provide five principles of effective hazard perception test creation, which they used in the creation of a computer based hazard perception test to be used for licensing purposes in Queensland, Australia. Firstly, they suggest that hazard perception tests should not include any active hazards such as items measuring tailgating, gap acceptance, overtaking behaviour, or speed choice; as these types of items have previously been found to load onto a separate component to hazard perception. Secondly, in the development of a hazard perception test, careful consideration should be given as to whether each scene provides anticipatory cues to enable a driver to predict how hazardous events are likely to develop. Their third recommendation is that hazard perception tests should only contain genuine, unstaged scenarios. Instructions for a hazard perception test should be unambiguous in the definition of what a hazard entails. Finally, a hazard perception test should be able to identify and classify inappropriate responses, thereby facilitating the detection of people over-responding or trying to cheat the test. Using these principles a hazard perception test was designed for use in the Queensland context. Hazards were selected based on the ratings of expert driving instructors. Results indicated that there was a significant difference in the response time of experienced drivers (more than 15 years' experience) and novice drivers (average 4.2 months experience), with experienced drivers responding considerably faster than novice drivers. Novice drivers also missed significantly more traffic conflicts than experienced drivers. These guidelines may be useful in the design and development of future hazard perception tests, and may provide the grounds for more standardisation of the content of tests.

1.4.2 Use of Hazard Perception Testing in Licensing

As a result of the research linking hazard perception skill to crash risk, a number of jurisdictions have incorporated a hazard perception test into their licensing procedure. There is some evidence that these tests have been useful in reducing accident liability of drivers, although this may only occur in limited situations. In 2002, a hazard perception test was incorporated into the UK driver testing system. The test requires participants to watch a series of video clips and respond with a button press when a hazard is detected (Jackson et al., 2009). Recent research has shown that drivers who have passed the hazard perception test have, on average, a lower accident liability than those who did not take the test, even when variables such as age, sex, experience and exposure were taken into account. However, these results were only apparent for non-low-speed public road accidents and the hazard perception test did not appear to affect accident liability in other types of collision (Wells et al., 2008). Hazard perception tests have also been incorporated into the licensing regime in certain parts of Australia and New Zealand. In Australia, a number of different jurisdictions have introduced hazard perception testing. The Victoria hazard perception test has been used since 1996 to screen novice drivers for their ability to make safe driving decisions. While the first version of the test was found to have limited power in detecting certain types of crashes, there were problems with the reliability of the test (Ferguson, 2003). A more recent version has been developed but as of yet there is no evaluation of its effectiveness.

1.5 Training Hazard Perception

Despite the fact that current driver training programmes have shown very little benefit in terms of safety, driver education rarely provides a focus on higher order skills such as hazard perception (Mayhew, 2007). Research by Groeger and colleagues has shown that the instruction given to learning drivers across lessons reduces as a power function of the amount of practice the pupil has had. This effect reflected the number of times specific, individual manoeuvres had been repeated rather than time spent behind the wheel as a whole (Groeger & Clegg, 2007), and the relationship continues after official training, meaning novice drivers are continuing to learn well after they have passed their driving test (Groeger, Brady, & Britain, 2004). Interestingly, the one area of driving training where instructor comments do not decrease in a power function is where comments were concerned with appreciation of risk and likely behaviour of other drivers (Groeger, 2001). Comments making use of the terms ‘risk’, ‘danger’ and ‘hazard’ comprised only two per cent of all instruction given. This suggests that, despite the evidence linking hazard perception skill and crash involvement, drivers are not receiving adequate training in how to perceive and deal with hazards on the road.

The current section provides information on what we would expect from a driver training programme, and outlines some of the attempts which have been made to develop hazard perception training.

1.5.1 Transfer of Learning

Safe driving depends on the transfer of what is learned during training to a wider range of circumstances than could ever be encountered during training (Groeger & Banks, 2007). Two types of transfer are commonly referred to in the literature. Near transfer refers to transfer to a similar context to the one in which the learning takes place; and far transfer refers to transfer to a dissimilar contest (Barnett & Ceci, 2002). Although the concept of transfer has been studied by psychologists for over a century (see Thorndike & Woodworth, 1901), there is still little consensus on when, or even if, transfer of learning occurs, with a number of studies failing to find any evidence that learning in one context can generalise to related problems in different contexts (Barnett & Ceci, 2002). Barnett and Ceci (2002) argue that one of the reasons for the continuing absence of concrete knowledge around transfer of learning is the lack of any taxonomic framework for studying transfer. In many cases the training contexts and the contexts in which near and far transfer are expected to take place are not clearly defined. Groeger and Banks (2007) have attempted to tackle this issue by providing a framework for the evaluation of transfer during driving which focuses on specifying the content of what is to be transferred and the circumstances in which this transfer is expected to take place. The content of transfer refers to the level of learned skills, the type of performance change expected, and the extent of memory demand required. The circumstances of transfer can refer to the physical, temporal, social or functional contexts surrounding learning and transfer. As driver training provides no benefit unless it can transfer to circumstances not previously encountered, it is important to gain an understanding of when this transfer could be expected to occur. This framework will be discussed more thoroughly in Chapter 5.

A number of studies have attempted, with varying success, to train hazard perception using simple PC based packages and simulator training. In order to evaluate the success of the training, aspects of both near and far transfer have been assessed. Various different techniques have been used including anticipation training, verbal commentary training and error training. These will now be discussed in more detail.

1.5.1.1 Commentary Training

A number of studies have made use of commentary training to improve participant's hazard perception scores in a traditional computer-based hazard perception test. Isler et al. (2009) found that training in which participants were instructed to provide a running verbal commentary about any hazards they detected in video scenarios, including potential as well as immediate hazards, led to a significant improvement in response times and detection rates in a post-training hazard perception test. After training, there was no difference in the hazard perception scores of trained novice drivers and experienced drivers; and the trained drivers detected more hazards than an untrained novice group. However, caution should be taken in generalising from the results as the performance of experienced drivers actually diminished after the commentary training, with the number of hazards detected decreasing from the pre-training trial. There were also a number of design issues with this study including poorly defined experience groups and a lack of consideration of potential hazards (see Section 1.4.1.3 for more detail).

Wallis and Horswill (2007) also found that a group of novice drivers who received commentary training responded significantly faster than untrained novice drivers. Both the trained novice group and the experienced group made significantly more responses during the hazard perception test than novice drivers. However, the three groups did not differ significantly from one another in terms of their hazard ratings. McKenna et al. (2006) found that even listening to a recorded commentary could improve hazard perception-reaction times. Participants watched a video while listening to a recorded commentary supplied by a police instructor. The commentary described how to locate and identify potential hazards. Results indicated that trained participants responded significantly faster to a computer based hazard perception test than untrained participants. They also gave significantly less risky responses on a battery of computer based tests designed to assess speed choice and gap acceptance behaviours. A second study showed that these responses only occurred in hazardous situations, showing that trained drivers were able to discriminate between hazardous and non-hazardous environments. These results suggest that hazard perception can be improved through both creating and listening to verbal commentaries about hazardous situations. However, as all of the studies were computer based, there is no evidence as to how this training would transfer to hazard handling while actually driving.

Crundall et al. (2010) have examined the impact of training in commentary driving on subsequent performance on a driving simulator. The training took place over a period of two weeks. Firstly, the novice drivers were given a classroom lesson which involved watching a video of a drive while listening to a commentary, and identifying and ordering potential hazards displayed. They were then given a two hour on-road training session in commentary driving by a police-trained driving instructor, with the aim of identifying hazards, prioritising them and predicting what might happen next. They were also given feedback on any potential hazards that they missed. Results indicated that the risk of a collision with other road users was significantly reduced after the training intervention. Pre- and post-training tests consisted of a 10 minute simulator drive containing hazardous events. Participants who had undergone training reduced their speed in relation to post-test hazards earlier, and to a greater extent than the control group, in particular in situations which required ‘dividing and focusing attention’ and ‘behavioural prediction’ skills (see Section 1.4.1.3). Acceleration and braking behaviour was also found to differ between trained and untrained participants in the post-training test. Although these results show the benefits of using commentary training to increase novice drivers hazard perception skills, it should be noted that the training failed to improve participant’s awareness of ‘environmental prediction’ hazards i.e. where the ultimate hazard is hidden from view. This is problematic, as these types of hazard have previously been shown to lead to the greatest differences between novice and experienced drivers (Crundall et al., 2012; Pradhan, Pollatsek, Knodler, & Fisher, 2009). In addition, the untrained control group did also show a slight reduction in collisions, and the untrained group had also demonstrated better performance on the simulator prior to training. This may be an indication that there was a slight practice effect of using the simulator, and that there was more room for the trained group to improve relative to the untrained group.

1.5.1.2 Anticipation Training

McKenna and Crick (1997) developed a training programme for novice drivers involving a classroom session, a group video session and a one-to-one session with video sequences. The focus for this training group was on encouraging participants to generate predictions about the likely outcomes of potential road hazards, with a lot of the emphasis on encouraging trainees to look further ahead in the visual field. The trainee group’s reaction times in a hazard perception test improved by about 0.5 seconds between the pre- and post-training tests, whereas there was no significant change in a control group's scores. A follow-up study showed that when prediction training and a general driver awareness training course were compared, only the prediction training led to significant improvements in reaction times (McKenna & Crick, 1997). The results of these studies suggest that prediction/anticipation training can be an effective means of training hazard perception reaction skills. However, the fact that only novice drivers were included in the studies means we have no knowledge of the level to which trained novice drivers hazard perception has improved. In addition, the novice drivers had up to four years' experience, which is much higher than other hazard perception studies (e.g. Crundall et al., 2012; Fisher, Pollatsek, & Pradhan, 2006). Finally, as this study once again made use of a computer based hazard perception test, it is unclear as to how the training would generalise to actual driving behaviour (Groeger, 2000).

Fisher et al. (2006) and Pradhan et al. (2009) used the Risk Awareness and Perception Training (RAPT) package, a PC based training regime, to train drivers on recognising two different types of hazard. They focused on situations in which a threat could potentially materialise, in other words, situations containing hidden risks (e.g. a pedestrian that may be obscured from drivers as they approach a crossing). They claimed that near transfer would be maximised when the cues necessary to retrieve the knowledge in the situation to which transfer is needed are directly present in the training situation. Far transfer occurs when the principles needed to generalise what one has learned are explicitly abstracted for the learner, i.e. by explaining why a situation is potentially risky. The RAPT PC based training package contains scenarios where there is an inherent risk of a collision with another vehicle or pedestrian. The training programme involved showing participants a top-down, schematic view of a scenario accompanied with explanations about the risky aspects of that scenario. Participants were then presented with the perspective view snapshots for that scenario (similar to those used in the tests) and given feedback on their performance in identifying locations which should be monitored. In a simulator test, trained novice participants were found to be more likely than untrained participants to fixate more on areas of the road which could reduce their likelihood of a crash in both near and far transfer situations. This effect was apparent even up to five days after the training (Fisher et al., 2006). Similar findings were also obtained in an on-road driving test, although in that condition, the difference between the groups was larger in the near transfer situations than in the far transfer ones (Pradhan et al., 2009). These results suggest that a PC based training programme can be successful in changing inexperienced young drivers gaze patterns, and that this relatively low-fidelity training can lead to both near and far transfer of learning to real world situations. However, there were no clear definitions of what near and far transfer situations entailed so the degree of transfer is unclear. In addition, we do not know if these changes in behaviour would last over time.

Chapman, Underwood and Roberts (2002) trained novices to look at critical areas of hazard perception clips, incorporating aspects of both verbal commentary training and hazard anticipation training. Participants were asked to provide a running commentary on films of potentially dangerous driving situations with and without the support of markers overlaid on the screen which represented the areas experienced drivers looked at. They were then asked to view more driving clips and to anticipate what was going to happen next in the scene. This led to shorter fixation durations and a wider horizontal spread of search for novice drivers when they viewed subsequent hazard perception clips. This effect transferred onto real-world driving, with the trained novice drivers showing an increased spread of horizontal visual search after the training intervention. The visual search patterns of untrained novice drivers did not change. In a follow up evaluation approximately three months later, the changes in eye-movements were still detectable in a simulator setting but not on the real roads. This study demonstrates the potential for training novices' visual search patterns using commentary and anticipation training, but also the limited transfer from simulated environments to the real world environment as evidenced by the diminishing effect over time.

Wang et al. (2010) included three different parts in their driving training programme. Firstly, participants drove through a number of hazardous situations in a driving simulator. They then viewed a playback video of their own hazard handling performance as well as a video of an experienced drivers' hazard handling performance. This training incorporated aspects of both error training and anticipation training, along with training in detection and recognition of hazards. Hazard handling performance was rated by two independent assistants. It was found that trained novices had better hazard handling scores than untrained novices.

However, as the average consistency rate between the two assessors was 69.5%, it is possible that these results do not provide a fully objective measure of performance. The trained novices also anticipated hazards designed to evaluate both near (i.e. the same risk elements in a different traffic environment) and far transfer (i.e. the same strategies were required to detect potential hazards) significantly better than untrained novices in a post-training test. However, the measure of hazard anticipation was weak as it involved participants watching a replay of their driving test and giving self-ratings of the extent to which they had anticipated the hazard. Analyses of speed behaviour showed that trained novices drove significantly more slowly throughout the test drive. Trained participants also tended to reduce their speed more dramatically in the final 30 metres before the onset of hazards than the untrained group. These results show the benefits of incorporating a number of different training methods into any driving intervention. Participants hazard anticipation skills were improved, as highlighted by their speed behaviour. In addition, levels of mental workload were decreased. However, the article does not provide huge detail on the content of the training so it is difficult to evaluate where any improvements in performance might have occurred. In addition there was no baseline measure of behaviour so it is possible that the trained group were better than the untrained group prior to any training.

1.5.2 Summary of Training Results

The studies described above provide some positivity regarding the trainability of hazard perception skill. It appears that participants can be taught to respond to hazards more quickly, at least in computer-based response tests. It would also appear that drivers can be taught to scan for hazards more effectively in both simulated and on-road environments. This suggests that some transfer of learning can occur from laboratory to actual on-road driving, although it is not clear how long any changes in behaviour will last (Chapman et al., 2002). Groeger (2000) argues that in order for transfer of learning to take place, some verbal mediation or declarative coding of information must take place. The studies providing evidence for transfer of learning all involve some verbal representation of knowledge, providing support for this idea. However, it is unlikely that in real-time driving, there would be enough time for deep verbal processing to occur prior to any hazard response decision-making. In addition, none of the studies provided definitive descriptions of what exactly near and far transfer of learning entailed. These concepts must be clarified if we are to gain a full understanding of exactly when and where transfer of any learning regarding hazard perception is expected to occur.

1.6 Purpose of Research

Although hazard perception is one of the most commonly studied concepts in driving psychology, there is still little consensus on what exactly it entails. Much of the research to date has focused on response times to hazards presented on a computer screen (e.g. McKenna & Crick, 1997; Sagberg & Bjørnskau, 2006; Wallis & Horswill, 2007), and it is generally considered that the extra time available to participants who perform faster on this type of test confers a safety advantage in terms of appropriate action selection (Groeger, 2000). However, Groeger’s (2000) Cognitive Account of Driver Behaviour highlights the importance of taking into account both the process of initially detecting a hazard, and the process of responding to that hazard. The framework separates out the elements of hazard detection, appraisal of inherent threat, the selecting of a response action, and the implementation of that action. One of the main aims of this thesis is to use that model to compare performance on a simple hazard detection test where no decisions about response type are required, to a more complex test incorporating both action selection and implementation (hazard handling). Chapters 2 and 3 will discuss the development and evaluation of these tests.

A second issue which has arisen in the literature surrounding hazard perception is its trainability. Current driver education systems provide little emphasis on the training of higher order skills such as hazard perception. Although there is some evidence that hazard detection skills can be improved through training (Isler et al., 2009; McKenna & Crick, 1997; Wallis & Horswill, 2007), these studies provide no evidence as to how this improvement in hazard detection would map on to actual hazard handling. The simulator and on-road studies conducted in the University of Massachusetts (Fisher et al., 2002; Fisher et al., 2006; Pradhan et al., 2009) and University of Nottingham (Chapman et al., 2002; Crundall et al., 2010) provide optimism that hazard handling skills can also be trained, but do not provide enough information on the level of overlap required between training and transfer contexts. Chapters 4 to 6 of this thesis will outline the results of two different training programmes focusing on different aspects of driver perception and awareness. Transfer of learning will be statistically defined to provide a deeper understanding of the context and circumstances in which it might be expected to occur.

2 Chapter 2: Developing Measures of Hazard Detection and Hazard Handling

In Chapter 1, the Cognitive Account of Driving of Groeger (2000) was outlined. This model contains mechanisms for both perceiving and responding to hazardous events, and thus this Chapter will outline two types of test designed to tap into these different aspects of hazard perception.

2.1 Introduction

One of the most important aspects of driving behaviour is the ability to anticipate and make predictions about the driving environment. An ability to predict how a traffic scene will progress allows the skilled driver to avoid potentially hazardous situations (McKenna & Crick, 1997). Hazard perception is a concept which has been studied for over 40 years (Grayson & Sexton, 2002); and hazard perception skill has been suggested as the most likely source of any skill gap between novice and experienced drivers. It is the only domain-specific skill that has been found to correlate with drivers' accident records across a number of studies (Horswill & McKenna, 2004). It is generally accepted that experienced drivers respond more quickly than novice drivers to hazardous events occurring on the road (Crundall et al., 2012; Groeger, 2000). However, different methods of hazard perception measurement have had varying degrees of success in establishing this relationship (Chapman & Underwood, 1998).

2.1.1 Measuring Hazard Perception

In Chapter 1, a number of the most commonly used methodologies for measuring hazard perception were discussed in detail. The most common method is to focus on the perception-reaction time to perceived hazard (Borowsky et al., 2009; Groeger, 2000; Groeger & Chapman, 1996). In tests using this methodology, drivers are asked to observe traffic-scene movies or pictures, and to press a response button as soon as they detect a hazard (Chapman & Underwood, 1998; Sagberg & Bjørnskau, 2006; Wallis & Horswill, 2007). Some researchers have questioned the validity of using response time alone to measure drivers' hazard perception abilities (see Groeger, 2000; Jackson et al., 2009), leading to many authors using a mixed methodology to examine hazard perception skill. Studies have examined other aspects of hazard perception such as visual fixation patterns (e.g. Chan et al., 2010; Crundall et al., 2003; Velichkovsky et al., 2002); hazard classification (Borowsky et al., 2009); hazard location identification (Fisher et al., 2002; Smith et al., 2009; Whelan et al., 2002); and speed choices (Wang et al., 2010).

In the majority of the tests described above, participants' reactions were measured in simulated environments, often involving films recorded from the driver's eye position. Although none of these studies have investigated actions taken after the hazards have been detected, it is widely assumed that the additional time available for drivers who respond more quickly confers a safety advantage (Grayson et al., 2003; Groeger, 2000; Groeger & Chapman, 1996). However, this is not necessarily the case and according to Groeger's (2000) model, the process of successfully avoiding a driving hazard must take into account what happens after the hazard is initially perceived. This theoretical framework argues that in order to deal with driving risks drivers must first detect the presence of a hazard and appraise the threat contained, after which they must select and implement an appropriate hazard response (e.g. slowing down/steering to the left or right). Therefore, this chapter will focus on both the initial detection of hazardous events, and the actual driving response made to handle the hazard.

2.1.2 Defining Hazard Situations

An in-depth discussion of the various definitions of hazard perception is provided in Section 1.2 of Chapter 1. The focus in this thesis is on the theoretical model outlined in Groeger (2000) and Grayson et al. (2003) which separates the process of responding to a risk into four components of hazard detection, threat appraisal, action selection, and implementation. Hazard detection refers to becoming aware that a hazard may be present; threat appraisal involves the evaluation of whether the hazard is sufficiently important to merit a response; action selection refers to the process of selecting a response from one's repertoire of skills; and implementation is the performance of the necessary actions involved in the response that has been selected. This model provides a useful means for thinking about the hazard perception and reaction process, as it describes both the subjective and skill elements of the concept. However, in order to evaluate drivers' responses to hazardous situations, it is necessary to establish what constitutes a driving hazard. This is a very important issue, as an evaluation of the introduction of the British hazard perception driving test suggests that benefits of this type of test may be limited to quite specific driving situations e.g. non-low-speed reported public road accidents (Wells et al., 2008). The lack of awareness of the impact of specific types of hazard may provide some explanation for the inconsistencies in the results of hazard perception tests to date.

The few hazard perception studies that have focused on the specific types of hazard which discriminate effectively between novice and experienced drivers (see Crundall et al., 2012) are discussed in Chapter 1 and will be briefly summarised here. Sagberg and Bjornskau (2006) failed to find an overall difference between novice and experienced drivers response times to a video based hazard test. However, they found that experienced drivers did show significantly faster response times than novices to six individual hazard situations (e.g. a pedestrian unexpectedly taking a step towards the kerb, a parked car ahead pulling out from the kerb). The authors suggested that there may be particular hazards for which the gap between novice and experience drivers is bigger than others.

Two recent studies by Scialfa et al. (2012; 2011) provide further evidence for this idea. They used both short video clips of hazards and still images of driving scenes to examine the hazard perception skill of novice (less than 6 months experience) and experienced drivers (more than 2 years' experience). Participants were asked to identify traffic conflicts as quickly as possible, and to rate the level of hazard and visual clutter in the scene. Novice drivers had significantly slower composite response times than experienced drivers to the traffic conflicts in both studies. However, a further analysis of the static scenes showed only eight individual scenes (out of 120) where the difference reached statistical significance, once again suggesting that certain hazards may be better at discriminating between experience groups than others. A shortened test, based on the most discriminating scenes, also showed that novice drivers had significantly slower response times to hazards, and a significantly lower hit proportion than experienced drivers. However, little information was given on the nature of the discriminating scenes and there was no attempt to categorise which features of these scenes made them more likely to differentiate between drivers.

As the Scialfa et al. (2012) study shows, many hazard perception tests are based on a post-hoc analysis of the situations which provide the most discrimination between novice and experienced drivers, with little attempt to provide a theoretical framework as to why novice drivers may have poorer ability to deal with particular hazards. In a simulator study of hazard perception, Crundall et al. (2012) attempt to tackle this issue by providing a-priori definitions of the categories of hazards included in their test. They distinguished between three main categories of hazard; behavioural prediction hazards, environmental prediction hazards and dividing and focusing hazards. Behavioural prediction hazards occur where drivers can predict a hazardous situation by identifying a potential hazard and assessing its attitude, position and trajectory (e.g. a pedestrian standing at the side of the road who could walk out in front of the driver); and environmental prediction hazards occur where drivers can identify that the environment through which they are driving may contain a hidden hazard (e.g. a parked truck which may be hiding a pedestrian). Finally, dividing and focusing attention scenarios contain more than one hazard precursor meaning drivers need to monitor both precursors before focusing on the eventual hazard (e.g. a parked bus on one side of the road, and a pedestrian on the other side) (Crundall et al., 2010; Crundall et al., 2012). In a simulator study, it was found that novice drivers were particularly poor at noticing environmental prediction hazards and were likely to miss these altogether (Crundall et al., 2012). This provides support for Sagberg & Bjørnskau’s (2006) idea that different hazards may be more/less successful in discriminating between experience groups.

In order to investigate this idea of variations in responses depending on the individual characteristics of the hazard situation, this study will focus on two types of hazard. Firstly, the focus is on hazardous situations which arise through interactions with other road users i.e. pedestrians and other vehicles. Pedestrian events occur when the movement of a pedestrian in the environment causes a hazard situation to arise. Events involving other vehicles arise when their movement causes a hazard situation either through their pulling out and partially blocking the forward roadway (car emerging events), or through a parked car moving to enter the traffic flow ahead (merging traffic events). The specific characteristics of this movement (e.g. how visible a pedestrian is) will influence the level of threat the driver feels and thus could be expected to influence hazard responses. The second type of hazard focuses on drivers' interactions with the environment i.e. their behaviour around bends and traffic lights. Once again, the specific characteristics of the environment will influence driver reactions. Amber onset at a traffic light will cause a different level of threat depending on the driver's location in relation to the traffic light, and bends will vary in the level of difficulty negotiating them. Thus, this study will focus both on the individual hazard scenarios which may discriminate between novice and experienced drivers, and on the specific characteristics of those situations which may influence response.

2.1.3 Simulator Technology

Hazard perception research has generally taken place using a computer based test involving a pre-recorded film of driver behaviour. The current study will take place in a more immersive driving simulator. Driving simulators are usually categorised as being either high-level, medium-level or low-level simulations, although the distinctions between these levels are not always clear. Research across a variety of domains (e.g. speed/lateral position) has found that although absolute correspondence between simulated and real-world environments is generally low, relative correspondence can be quite high (Blana, 1996; Törnros, 1998). Each of the simulator types has advantages and disadvantages in terms of driving research.

According to Decina, Gish, Staplin, and Kirchner (1996) the most advanced, high-level simulators are operated by numerous specialized computer programmes and have the highest fidelity visual and motion systems, with at least 180° front field of view and a motion based platform. These high-fidelity simulators provide strong levels of physical validity, but are also very expensive, and cannot be moved from place to place. Medium level (mid-level) driving simulators provide advanced imaging techniques, a large projector screen, and all of the normal vehicle controls. They can be fixed base or can provide trivial motion cues by using systems which simulate the normal vibrations and sounds experienced while driving. They provide many of the physical cues present in a real car, and generally have a wide forward field-of-view, which can be supplemented by rear-mirrors to provide information regarding the rear of the car (Blana, 1996). Medium level simulators are less expensive, while still providing high levels of physical validity, and research by Blana (1996) found little evidence to support the hypothesis that moving-based simulators were better than fixed-base simulators in terms of measuring driving performance. However, the one main advantage of the moving-based simulators was a decrease in simulator sickness, a common problem in driving simulator research (Allen, Cook, & Rosenthal, 2001; Fisher, Rizzo, & Caird, 2011; Godley, Triggs, & Fildes, 2002). This is less of a problem for low-level PC based simulation as the reduction of optic flow in these systems leads to less sensory conflict between visual cues and vestibular movement (Fisher et al., 2011). However, PC based systems lack the ecological validity of medium level simulators, and also have a restricted field of view. Kemeny and Panerai (2003) reviewed a number of driving simulation experiments which looked at the manner in which drivers act upon speed and lateral position. They recommend that a horizontal view of at least 120° is needed for accurate speed perception in a simulator.

Allen, Park, Cook, and Fiorentino (2007) provide one of the few studies to compare performance on different driving simulators. Over five hundred novice drivers were given training in perceptual, psychomotor, and cognitive skills on one of the three STISIM simulators, namely a single monitor narrow field of view PC desktop system (NFOVD), a three monitor wide field of view PC desktop system (WFOVD), and a driving cab with wide-field-of-view system (WFOVC). Participants were presented with six 12-15 minute training scenarios with performance scores displayed at the end of each run. If performance criteria were met at the end of the sixth run, then participants were graduated. If unsuccessful, they could perform up to three additional trials. Performance measures included elements such as lane and speed deviations, speed limit and traffic signal violations, turn signal errors, hard cornering and braking, accidents, run completion time and median time to collision for all vehicle encounters. Results indicated that there was a general improvement from the first to the sixth trial in all three simulator configurations. However, the single monitor desktop configuration (NFOVD) led to the most speed limit violations and more aggressive driving behaviour than the other configurations. Students driving the cab simulator (WFOVC) showed the most conservative driving behaviour throughout (Allen, Cook, & Park, 2005). Accident data for the participants was obtained from the California Department of Motor Vehicles, allowing over two years of accident data for each group. These statistics were compared with teen driver accident rates for California published by Janke, Masten, McKenzie, Gebers, and Kelsey (2003) and similar rates for Nova Scotia in Canada published by Mayhew et al. (2003). A comparison of the accident statistics for each group of trained participants indicates that accident rates for the WFOVC and WFOVD groups are reliably lower than the traditionally trained drivers in California and Canada. The accident rate of the WFOVC group was also reliably lower than the WFOVD group. These results continued to be apparent for up to two years after training. The fact that the effects were greater for the WFOVC group suggests that full sized projected displays are significantly superior in their training value to smaller monitor presentations. The wide field of view also appears to be important as groups trained on the single monitor display (NFOVD) only had a slight improvement in accident rates over that of the general population (Allen et al., 2007). This provides some initial evidence that the type of simulator used can alter driving behaviour. However, the authors provided little information regarding the numbers who graduated from training, or the difficulties encountered on each individual simulator. Therefore, the cause of any simulator differences is not fully explained.

The research into hazard perception skill to date has generally made use of low-level PC based simulator technology in which participants view a driving scenario and push a button when a hazard appears (Chapman & Underwood, 1998; Sagberg & Bjørnskau, 2006; Wallis & Horswill, 2007). Although this method has provided a measure of hazard perception which discriminates between novices (less safe) and experienced (presumably safer) drivers, it does not provide a mechanism for understanding how hazard detection links to actual driving behaviour. Therefore, this study will make use of a medium-level driving simulator which will allow the measurement of hazard detection skill and hazard handling skill using a wide field of view.

2.1.4 Study Aim and Research Questions

The purpose of the studies in this chapter is to develop a measure of hazard perception that is relevant in an Irish context and can discriminate between experienced (safe) and novice (less safe) drivers. Traditional measures of hazard perception have focused on simple button press responses to hazards presented on a computer screen. Previous research has not looked at how these hazards are handled when people are actually driving. This study will discriminate between hazard detection and hazard handling tests to try to determine what, if any, relationship exists between simple button press responses and actual driving behaviour. This will allow us to evaluate both the detection and implementation aspects of hazard perception outlined by Groeger (2000) in a fully immersive simulator environment. As previous research has generally failed to discuss the impact of individual hazard variables on participant's response times, hazards in this study will be evaluated at both an individual and group level to try to develop a clearer understanding of what types of hazard discriminate between novice and experienced drivers.

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Novice drivers will signal the presence of hazards more slowly than experienced drivers in an immersive simulated environment
- Hypothesis 2: Novice drivers will respond more slowly than experienced drivers in a hazard handling test, which requires drivers to change their actual driving behaviour in response to hazards.
- Hypothesis 3: The benefits of experience will vary across hazards, providing a better understanding of the threat appraisal process in hazard responding.

2.2 Method

2.2.1 Participants

A total of 42 participants volunteered for the study, 22 males and 20 females. In order to monitor the well-being of participants an adapted version of Kennedy, Lane, Berbaum, and Lilienthal (1993) simulator sickness questionnaire (SSQ) was administered before and after each drive in the simulator (see Appendix A). As a result of scores on this questionnaire, a total of five participants had to withdraw at various stages. As can be seen in Table 1, participants had the highest level of discomfort after the first test condition, and that this did not change significantly with increased exposure to the driving simulator. The participants who withdrew either had a total score of greater than 5 or reported "moderate" or "severe" discomfort in respect of any of the symptoms.

Table 1: Comparing Simulator Sickness Questionnaire scores before and after each simulator drive

Comparison Groups	M	SE	Df	t	p	Cohen's *d*
1. Pre-Practice	0.91	0.25	42			
2. Post-Practice	1.12	0.28	42	-1.36 (2-1)	0.18	0.12
3. Post Hazard Test 1	2.13	0.54	40	-2.76 (3-2)	0.01	0.44
4. Post Hazard Test 2	1.38	0.34	37	-0.28 (4-3)	0.78	0.05

Therefore, 37 participants completed the hazard detection study, 20 males and 17 females; and 38 participants completed the hazard handling study, 20 males and 18 females. The novice drivers had less than two years total driving experience (M=0.94yrs, SD=0.75) with an age range of 18.95 years to 25.03 years (M=20.91yrs; SD=1.51). The experienced group had between 5 and 15 years driving experience (M=8.52yrs, SD=2.48) and an age range of 22.01 years to 43.11 years (M=27.72yrs; SD=4.55). The groups differed significantly in terms of experience ($t(38)=-13.81$, $p<.001$); and age ($t(38)=-6.71$, $p<.001$).

Participants were recruited through the use of University College Cork's (UCC) student mailing list, advertisements posted around the UCC campus, and through the development of a Facebook profile. All participation was voluntary and informed consent was obtained prior to participation.

2.2.2 Apparatus

2.2.2.1 Driving Simulator

Both hazard perception tests took place in UCC's driving simulator, which consists of a full-size Volkswagen Polo vehicle with manual transmission. It has 7.1 Dolby surround sound and a 135 degree field of view, resulting from image projection onto three wall-to-floor screens located approximately one to one-and-a-half metres from the car body. This immersive, fully interactive, visual environment is supplemented with active wing and rear view mirrors. A network of five PCs underlie the STISIM 400W and permit the real time display of complex traffic scenes, including other traffic, and pedestrians who behave realistically in response to the simulator-drivers' actions. Simulator output includes information on driver's speed, road position, and all pedal, steering wheel and ancillary dashboard controls at 20Hz.

Figure 3: STISIM 400W Driving Simulator

2.2.2.2 Tests of Hazard Detection and Hazard Handling

The same hazard perception drive was used in both the detection and handling conditions. The drive consisted of five different speed zones i.e. 25kph, 40kph, 60kph, 70kph and 100kph; each containing various types of hazards including bends of different curvature, traffic lights with amber onset at different times, visible and hidden pedestrians, car emerging events and following tasks. The speed zones were counterbalanced to control for any ordering effects as follows:

Drive 1: 40kph, 100kph, 25kph, 70kph, 60kph
Drive 2: 60kph, 25kph, 70kph, 40kph, 100kph
Drive 3: 25kph, 60kph, 40kph, 100kph, 70kph
Drive 4: 70kph, 25kph, 60kph, 100kph, 40kph

The hazards included in the drive were selected based on an analysis of the Road Safety Authority (RSA) accident database which consists of information on all recorded accidents on Irish roads from 1997-2007, along with information from the literature on previously effective hazards. Based on these analyses five types of hazard were included in the hazard perception tests. These were car emerging events, merging traffic events, pedestrian events, traffic light events, and bends. The drives took place on a two-lane road (lane width=3.66m), which moved through both rural and urban environments.

2.2.2.2.1 Car Emerging Events

For car emerging events, a car parked perpendicular to the road emerged in front of the participant as they approach.

Figure 4: Example of Car Emerging Event

The car was initially parked 8.6 metres from the roadway dividing line, and started to move when the participant was 4 seconds away. The car moved 4.3 metres into the roadway, partially blocking the driver’s lane (see Figure 4). There were a total of three car emerging events in the drive (25kph, 40kph, 100kph).

2.2.2.2.2 Merging Traffic Events

In the merging traffic events, a car parked parallel to the road suddenly pulled out from the near side of the road to enter the traffic flow, travelling at the posted speed limit. The car began to move when the participant was 3 seconds away (see Figure 5).

Figure 5: Example of Merging Traffic Event

There were four merging traffic events in the drive, one in the 25kph, 40kph, 70kph and 100kph speed-zones.

2.2.2.2.3 Pedestrian Events

In the pedestrian events a pedestrian walked out in front of the driver from the near side of the road and crossed to the opposite side of the road. There were two categories of pedestrian. *Pedestrians with continuous visibility* pedestrians were fully visible for the entire walking time before the driver reached them. The pedestrian was initially located 6.1m from the centre-line of the road, and started to move at a speed of 1.07m/s when the participant was 3 seconds away (see Figure 6). *Pedestrians with interrupted visibility* emerged from behind a parked van/truck. The pedestrian was initially located 12.2 metres from the centre of the road and started to move at a speed of 1.52m/s when the participant was 8 seconds away. They disappeared behind the parked vehicle for 1 second of their trajectory time.

Figure 6: Example of Pedestrian event with continuous visibility

There were a total of six pedestrian events, with one pedestrian with continuous visibility in each of the 25kph, 40kph and 70kph speed zones; and one pedestrian with interrupted visibility in the 40kph, 60kph, and 100kph speed zones.

2.2.2.2.4 Traffic Lights

Amber onset occurred when the driver was in different decision zones with respect to the traffic lights (*safe stopping, dilemma, & safe crossing zones,* see Figure 7). The timing of amber onset in each of the speed zones was calculated using the following formulae from Papaioannou (2007):

$$\text{Safe stopping zone (SSZ)} = Vop + (v_0^2/2dm)$$

$$\text{Safe crossing zone (SCZ)} = Vo\tau - (w + l)$$

$$\text{Dilemma zone} = SSZ - SCZ$$

Where Vo is the approaching speed of the vehicle, *p* the perception/reaction time, *d*m the maximum deceleration, τ the yellow time interval, *w* the width of the crossing road, and *l* is the vehicle length. A deceleration rate of 3.5 m/s^2 was used as representative of the majority of vehicles, and the perception/reaction time was taken as equal to 1.5s based on Papaioannou's (2007) research. The width of the crossing was 9.86m and the length of the vehicle was 4.17m. Table 2 shows the amber onset time for all three types of traffic lights across the various speed zones.

Table 2: Amber onset times for traffic lights in different speed-zones

Traffic Light Zone	25kph	40kph	60kph	70kph	100kph
Safe Stopping Zone	2.49s	3.09s	3.88s	4.17s	5.47s
Dilemma Zone	1.73s	2.35s	3.01s	3.25s	3.97s
Safe Crossing Zone	0.98s	1.74s	2.16s	2.28s	2.49s

Amber onset for traffic lights classified as being in the safe stopping zone occurred when participants' were far enough away from the traffic light that most people would be expected to come to a stop. For traffic lights classified as being in the safe crossing zone, amber onset occurred when participants were so close to the traffic light that most people could go straight through the intersection without any acceleration. Finally, amber onset classified as the dilemma zone occurred where neither decision was obvious as drivers would have to brake abruptly to come to a stop, or increase speed rapidly to clear the intersection

Figure 7: Example of Traffic Light Event

There were a total of 12 traffic light events, three in each speed zone.

2.2.2.2.5 Bends

Participants drive through a series of bends, some of which had *interrupted visibility* (see Figure 9) and some of which had *continuous visibility* (see Figure 8).

Table 3: Radius of curvature for bends in different speed zones

Curvature	25kph	40kph	60kph	70kph	100kph
Small	20m	30m	70m	100m	340m
Medium	35m	50m	170m	200m	660m
Large	50m	65m	190m	320m	880m

Bends with continuous visibility contained no impediments to vision throughout the bend. Bends with interrupted visibility were situated in an urban environment and it was not possible to see the other side of the bend. There were three levels of curvature, *small, medium, & large.* The radius of the bend depended on the speed zone (see Table 3).

Figure 8: Example of bend with continuous visibility

Figure 9: Example of bend with interrupted visibility

As can be seen in Table 3 bends with small curvature had the smallest radius and therefore, were the most difficult to negotiate. Large bends had a large radius, making them less sharp, and easier to negotiate. There were a total of 30 bend events, six in each speed zone.

2.2.3 Evaluating Responses

For the hazard detection condition, participant responses were recorded through a simple lever press response (lever circled in red on Figure 10). The measurement window for each hazard started from the point at which the hazard was triggered i.e. began to move, and finished when the participant had passed the hazard. Response time was recorded as the time taken from initial hazard trigger to the first lever press within this window.

Figure 10: Lever press to indicate hazard response in Hazard Detection test

In the hazard handling condition participants were driving themselves and there were no discrete indications of a hazard response. In order to decide what constituted a hazard response, changes in driving behaviour of 0.5 standard deviations, 1 standard deviation and 2 standard deviations from the participant's mean pedal/steering wheel position were evaluated from the point at which each particular hazard was triggered to the point at which the participant had passed the hazard (see Sections 2.2.2.2.1 to 2.2.2.2.5). Changes of 0.5SD provided the least sensitive criteria and produced a large number of responses, as the change in behaviour required was quite small. This presented a potential for false alarms i.e. claiming a response was made where it was not. Changes of 1SD provided a more sensitive criterion, and produced fewer responses than changes of 0.5SD. Changes of 2 SD from mean behaviour provided the most sensitive criteria; indicating large changes in behaviour from the mean, and giving the fewest number of responses (see Appendix B). However, there was a danger of missing responses with this criterion as it may have been too stringent to allow all responses to be recognised. All three criteria were examined, and changes of 2SD from the mean pedal/steering wheel position showed the greatest sensitivity in identifying differences between novice & experienced drivers. Thus, it was decided that a hazard response would be identified as any change in behaviour of 2SD from the mean after a particular hazard window was triggered.

2.2.4 Design and Procedure

On initial arrival at the driving simulator laboratory, participants completed an informed consent form, and a questionnaire which provided background information on age, gender, driving experience, and educational background (see Appendix C); along with the SSQ, which provided a baseline measure of their wellbeing. They then completed a 10 minute practice drive, after which the hazard detection/hazard handling test was explained in detail to them. For the hazard detection test all aspects of the drive i.e. speed, lateral position, headway etc. were controlled externally and participants were asked to sound the horn every time they saw a potential driving hazard. This was defined as "any situation in which a collision or near collision with another road user or external object could occur unless you take some type of evasive action (e.g. braking, steering etc.)" (adapted from Wallis & Horswill, 2007, p. 1181). For the hazard handling condition, drivers were instructed to drive as they normally would, and the word hazard was not mentioned. When the participants finished the first condition, they were given a 15 minute break prior to completing the second drive. The order in which the drives were presented was counterbalanced to account for any ordering effects. Each version of the test took approximately 25 minutes to complete. A mixed between-within subjects design was adopted for this study, with the performance of experienced and novice drivers being compared in terms of their reactions to the different types of hazard. There were two dependent variables in both the hazard detection and hazard handling tests:

- Drivers' response rate i.e. the number of hazards participants responded to either through pressing the horn in the hazard detection condition, or making a change in their pedal/steering behaviour of 2SD in the hazard handling condition.
- Drivers' response time i.e. how quickly after the hazard was triggered participants either made a horn response (hazard detection) or changed their driving behaviour (hazard handling)

The independent variables were participant's level of driving experience (between-subjects), and hazard category (within-subjects).

2.3 Results

In this section, the results of a series of analyses of variance examining the different response patterns of novice and experienced drivers will be presented. Two effect size statistics are presented in this Chapter. Cohen (1988) provides recommendations for interpreting each of these statistics. For any analysis of variance effect sizes are measured using partial eta squared. A value of η_p^2=0.01 signifies a small effect, η_p^2=0.06 signifies a moderate effect and η_p^2=0.14 signifies a large effect. Where the results of any t-tests are displayed the effect size used is Cohen's *d*. For this statistic a value of |*d*|=0.20 is a small effect, |*d*|=0.50 is a medium effect, and |*d*|=0.80 is a large effect.

2.3.1 Hazard Detection Test

Mixed between-within groups ANOVAs were conducted to compare the performance of novice and experienced drivers in responding to each of the separate hazard categories i.e. car emerging, merging traffic, pedestrians, traffic lights and bends. The results of these analyses are presented in the following sections.

2.3.1.1 Response Rate to Hazards

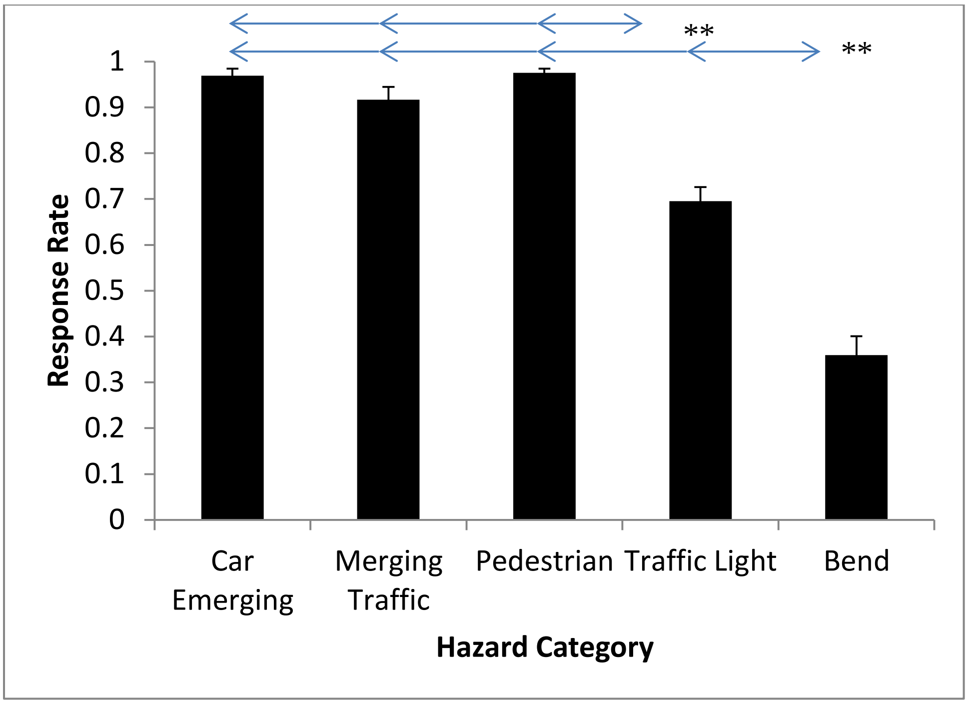
Overall, participants responded to a total of 78.73% of hazardous events (SE=0.15). A two-way mixed between-within groups analysis of variance was conducted to assess the impact of the within-group variable of hazard category (car emerging, merging traffic, pedestrian, traffic light, bend) and experience group (between-group variable) on the response rate to hazards. The results are presented in Table 4.

Table 4: Effects of experience group and hazard category on response rates in the Hazard Detection test

	Df	F	p	η_p^2
Experience Group	1,35	1.91	0.18	0.05
Hazard Category	4,32	100.78	<0.001	0.74
Hazard Category * Experience	4,32	0.36	0.84	0.01

Experience group did not have a significant effect the detection rate of hazardous events ($F(1,35)=1.91$, $p=0.18$), with experienced (M=0.80, SE=0.02) and novice drivers (M=0.76, SE=0.02) responding to a similar number of hazard events.

There was a large, significant effect of hazard category on detection rate ($F(4,32)=100.78$, $p<0.001$, $\eta_p^2=0.74$), displayed in Figure 11 below.



**p<0.01

Figure 11: Response rates to hazard categories in Hazard Detection test (mean values, error bars represent standard error)

A post-hoc Bonferroni comparison showed that participants made significantly fewer responses to bends than to any other hazard ($p<0.001$). They also responded to fewer traffic light hazards than pedestrian, car emerging and merging traffic hazards ($p<0.001$). There were no significant differences in the numbers of pedestrian, merging traffic and car emerging hazards identified.

The literature has shown that it is difficult to separate the effects of age and experience on hazard perception skill (Groeger, 2000). Therefore, it was important to examine the influence of participants' age on the results of this study. In order to do this, an analysis of covariance was conducted to control for any age effects (see Table 5).

Table 5: Effects of experience group and hazard category on response rates in the Hazard Detection test, with age as a covariate

	Df	F	p	η_p^2
Age	1,34	1.07	0.31	0.03
Experience Group	1,34	2.96	0.10	0.08
Hazard Category	4,31	1.21	0.31	0.03
Hazard Category * Experience	4,31	0.19	0.94	0.01

Participant age did not have a significant effect on the response rate to hazardous events (F(1,34)=1.07, p=0.31). When the effects of age were taken into account, there was no significant effect of experience on response rate to hazardous events (F(1,34)=2.96, p=0.10). However, an analysis of the means shows that novice drivers (M=0.75, SE=0.03) responded to fewer hazards than experienced drivers (M=0.81, SE=0.02), and the medium effect size of 0.08 suggests that this may be a meaningful difference. The significant effect of hazard category disappears when the effects of age are taken into consideration (F(1,34)=1.21, p=0.31).

The hazard detection test measures the number of hazards detected using a traditional discrete response type test in an ecologically valid, immersive driving environment. The results indicate that when the effects of age are included, there is a trend for novice drivers to detect fewer hazards than experienced drivers, although a larger sample size may be required for this to reach significance. It would appear that participants make fewer responses to elements of the driving environment such as bends and traffic lights than to hazards involving other road vehicles and pedestrians. However, this effect disappeared when age was included in the model.

2.3.1.2 Response Time to Hazards

Response time to a hazard was taken as the time from the initial triggering of the hazard event to the first press of the horn before the event ended. Overall response latencies to each hazard category were computed by averaging across response times to each individual presentation of that hazard. Missing values for a particular hazard were replaced by the overall mean response time to that hazard, a similar solution to that adopted in the research of McKenna and Crick (1997) and Horswill and colleagues (Horswill & McKenna, 2004; Horswill et al., 2009; Wallis & Horswill, 2007). This led to the replacement of 21.7% responses (a result of a low response rate to bends).

Figure 12 shows the distribution of response times to all hazards presented in the hazard detection test.

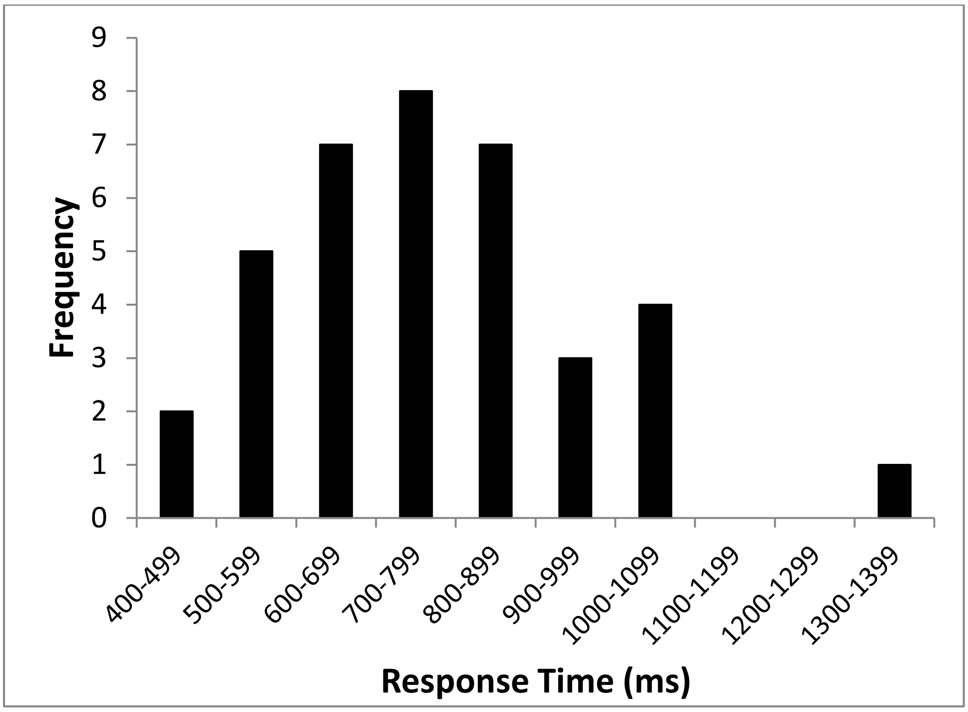


Figure 12: Distribution of response times in the Hazard Detection test

The distribution is relatively normal in shape and an analysis of the Kolmogorov-Smirnov statistic shows a non-significant result indicating normality (Kolmogorov-Smirnov $z(37)=0.58$, $p=0.89$). Therefore, it was not necessary to transform the data prior to conducting further analysis.

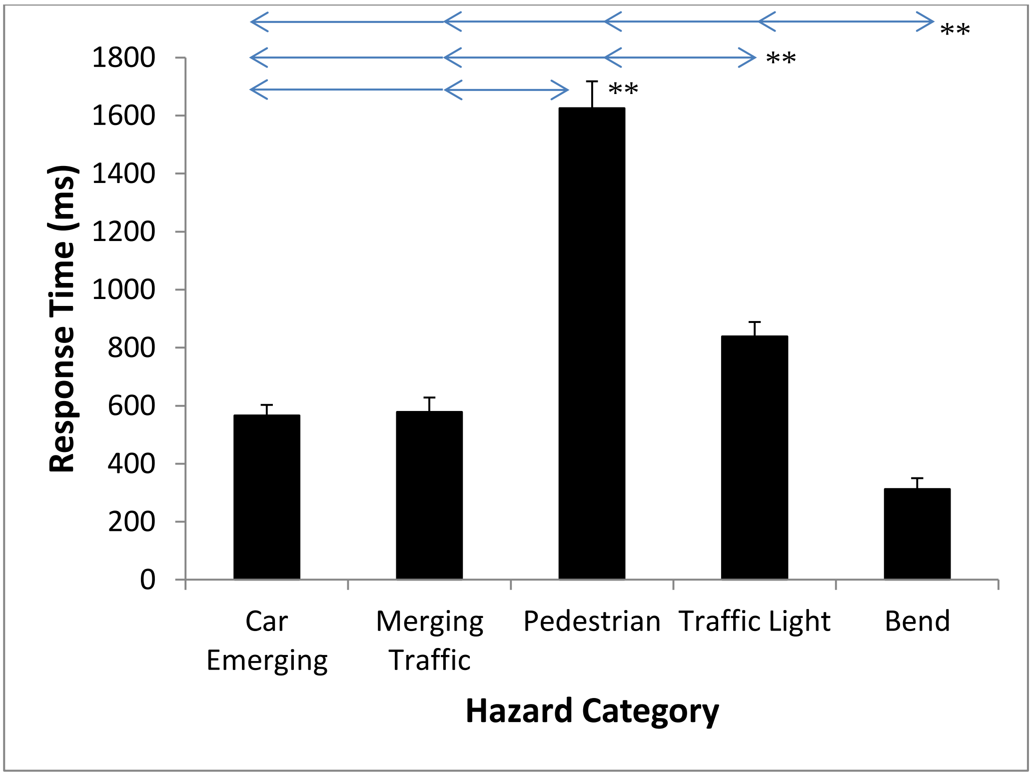
A two-way mixed between-within groups analysis of variance was conducted to assess the impact of experience group (between-group variable) and hazard category (within-group variable) on the response times to hazards (see Table 6).

Table 6: Effects of experience group and hazard category on response times in the Hazard Detection test

	Df	F	p	η_p^2
Experience Group	1,35	1.20	0.28	0.03
Hazard Category	4,32	115.11	<0.001	0.77
Hazard Category * Experience	4,32	1.66	0.17	0.05

Experience group did not have a significant effect on response time to hazardous events in the hazard detection test ($F(1,35)=1.20$, $p=0.28$), with experienced ($M=750$ms, $SE=40$) and novice drivers ($M=820$ms, $SE=50$) taking a similar length of time to respond.

Hazard category had a large significant effect on response time ($F(4,32)=115.11$, $p<0.001$, $\eta_p^2=0.77$; see Figure 13).



**p<0.01

Figure 13: Response times to individual hazard categories in hazard detection test (mean values, error bars represent standard error)

A post-hoc Bonferroni comparison of mean differences showed that participants responded significantly more quickly to bends than to any other hazard type

($p<0.01$). However, participants failed to respond to almost 65% of bends. Therefore, the fast response times are most likely not a true reflection of participants bend performance due to the vast number of cases replaced by a small mean. Response times to car emerging and merging traffic events did not differ significantly from one another (MD=10ms, $p=1.00$), but were significantly faster than response times to both traffic light (MD=260ms, SE=40, $p<0.001$) and pedestrian events (MD=1050ms, SE=80, $p<0.001$). It is clear that the slowest response time was to pedestrian events, which was significantly longer than response times to the other behavioural hazards. This is most likely due to the fact that there were two levels to the pedestrian hazard (continuous and interrupted visibility), suggesting that participants took longer to respond to the hidden hazard. However, this may also have been due to the fact that the response window for pedestrians with interrupted visibility (8 seconds) reduced the need for a fast response. This will be explored in greater detail in Section 2.3.1.4.

To take into account any effects of age on the initial response time results, a between-within groups analysis of covariance was conducted (see Table 7). The between groups variable was experience group, and the within-groups variable was category of hazard.

Table 7: Effects of experience group and hazard category on response times in the Hazard Detection test, with age as a covariate

	Df	F	p	η_p^2
Age	1,34	0.10	0.76	0.003
Experience Group	1,34	1.02	0.32	0.03
Hazard Category	4,31	2.72	0.03	0.07
Hazard Category * Experience	4,31	1.40	0.24	0.04

Age did not have a significant effect on the response time to hazardous events ($F(1,34)=0.10$, $p=0.76$), nor was there any significant effect of experience group apart from that explained by age ($F(1,34)=1.02$, $p=0.32$). The effect of hazard category remained significant, even when controlling for age effects ($F(4,31)=2.72$, $p=0.03$, $\eta_p^2=0.07$).

The response time results indicate that there were no differences between the time taken by novice and experienced drivers to make a horn-press response to events they considered hazardous in a simulator environment. Participants responded most quickly to bends, although the low response rate outlined in Section 2.3.1.1 means that this result should be treated with caution. Response times were slowest to pedestrian events. This will be explored further in the following section.

2.3.1.3 Example of Hazards Responses: Pedestrians and Traffic Lights

There were two types of hazard included in this study. One involved participant's interactions with other road users, in particular other car users and pedestrians. The other type of hazard event involved participant's interactions with fixed elements of the driving environment, in particular bends and traffic lights. In this section, a thorough analysis of both types of hazard will be conducted, focusing on pedestrian and traffic light events as examples.

2.3.1.4 Example of Hazards Involving Other Road Users: Pedestrians with continuous and interrupted visibility

There were two types of pedestrian hazard included in this study (see Section 2.2.2.2.3). There were three pedestrians with continuous visibility from the point at which they started to move, and three pedestrians with interrupted visibility who started to move, then disappeared behind a parked jeep for one second, before emerging onto the road. The pedestrians with interrupted visibility started to move when the participant was 8 seconds away, from a distance of 12.2m from the centre of the road. The pedestrians with continuous visibility started to move when the participant was 3 seconds away from a distance of 6.1m from the centre of the road.

Response frequency was averaged across the speed zones for pedestrians with continuous and interrupted visibility (visibility level). On average, participants responded to 98.2% pedestrian events. The results of a two-way between-within groups analysis of variance comparing experience groups (between groups) response rate to pedestrians with differing visibility levels (within groups) showed that experience did not have a significant effect on the response rate to continuous and interrupted visibility pedestrians ($F(1,35)=0.08$; $p=0.78$, $\eta_p^2=0.002$), nor did level of visibility have a significant impact ($F(1,35)<0.001$; $p=1.00$, $\eta_p^2<0.001$). Both experienced and novice drivers responded to an average of 98% of pedestrian events

(SE=1.20).To further explore the individual effects of both experience and age on response rate, an analysis of covariance on response rate to pedestrian events, including age as a covariate is presented in Table 8.

Table 8: Effects of experience group and pedestrian visibility on response rates to pedestrian hazards in the Hazard Detection test, with age as a covariate

Pedestrians	Df	F	p	η_p^2
Age	1,34	0.01	0.95	<0.001
Experience Group	1,34	0.06	0.80	0.002
Pedestrian Visibility	1,34	0.19	0.66	0.01
Visibility * Experience	1,34	0.09	0.77	0.003

Age did not have a significant effect on response rates ($F(1,34)=0.01$, $p=0.95$). Taking the effects of age into account did not affect the significance level of either experience group ($F(1,34)=0.06$, $p=0.80$) or visibility level ($F(1,34)=0.19$, $p=0.66$).

Response time was averaged across the speed zones for pedestrians with continuous and interrupted visibility (visibility level). Missing values were replaced with the mean response time for each particular pedestrian hazard leading to the replacement of 1.8% of responses. The results of a two way between-within subjects analysis of variance conducted to examine experience differences under the different visibility levels (continuous and interrupted) found that

Experienced (M=1545ms, SE=127) and novice drivers (M=1754ms, SE=145) took a similar length of time to respond to pedestrian events ($F(1,35)=1.18$; $p=0.29$, $\eta_p^2=0.03$). However, participants reacted significantly faster to pedestrians with continuous visibility (M=940ms, SE=60) than to those with interrupted visibility (M=2360ms, SE=160; $F(1,35)=106.76$; $p<0.001$, $\eta_p^2=0.75$). It should be noted that the pedestrians with continuous visibility were closer to the road when they began to move and this may provide an alternative explanation for the faster response times to this type of pedestrian.

In order to explore this finding further, an analysis of covariance on response rate to pedestrian events including age as a covariate is presented in Table 9.

Table 9: Effects of experience group and pedestrian visibility on response times to pedestrian hazards in the Hazard Detection test, with age as a covariate

Pedestrians	Df	F	p	η_p^2
Age	1,34	0.03	0.86	0.001
Experience Group	1,34	0.84	0.37	0.02
Visibility	1,34	2.85	0.10	0.08
Visibility * Experience	1,34	1.38	0.25	0.04

Age did not have a significant effect on response time to pedestrian hazards ($F(1,34)=0.03$, $p=0.86$), and taking the effects of age into account did not affect the significance level of experience group ($F(1,34)=0.84$, $p=0.37$). However, the previous significant effect of visibility level disappeared when age was included in the model ($F(1,34)=2.85$, $p=0.10$).

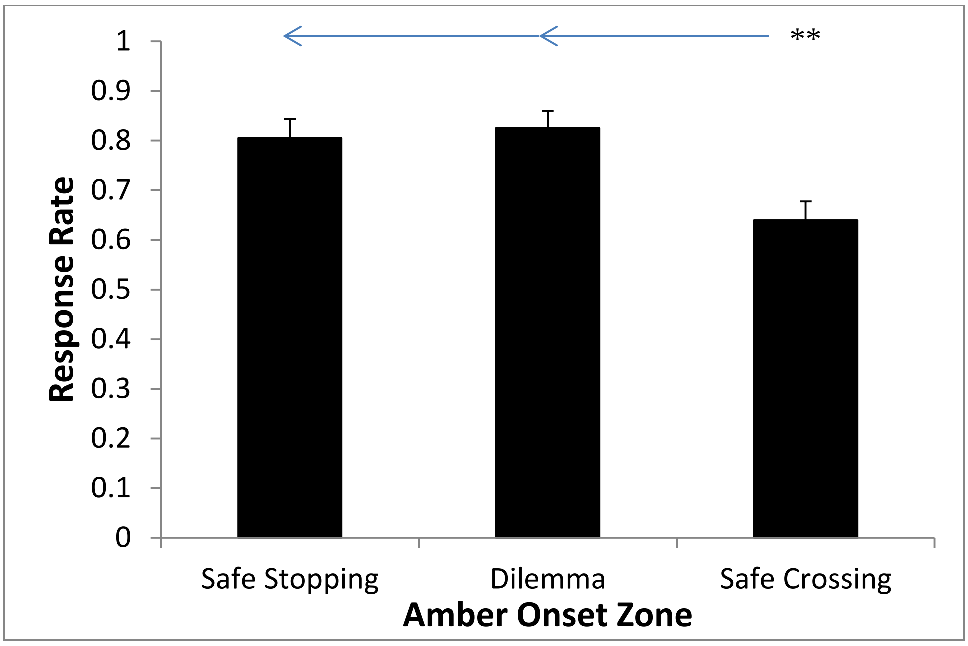
To summarize, it would appear that there was no difference between novice and experienced drivers responses to pedestrian events. Pedestrian visibility had a large effect on response times, with participants responding more slowly to pedestrians with interrupted visibility than to ones with continuous visibility. However, this effect disappeared when age was included as a covariate in the model.

2.3.1.5 Example of Hazards Involving Elements of the Traffic Environment: Traffic Light Events

This section will provide a further exploration of how participants responded to a fixed element of the traffic environment, namely traffic light events. Responses to traffic light events were averaged across speed-zones and two-way between-within groups analyses of variance on the response rate and response time to traffic light events were conducted. There were three levels of traffic light zone; safe stopping zone, dilemma zone, and safe crossing zone (see Section 2.2.2.2.4 for a full description).

The results of the analysis of variance examining the effect of experience group (between-group variable) and amber onset zone i.e. safe stopping, dilemma or safe crossing zone (within group variable) on response rate showed that experience did not have a significant effect on the response rate to traffic light events ($F(1,35)=1.11$, $p=0.30$, $\eta_p^2=0.03$), with novice drivers responding to an average of 72.4% of traffic light events (SE=4.7) and experienced drivers responding to an average of 79.0% (SE=4.1).

There was a large significant effect of amber-onset zone on response rate ($F(2,34)=17.33$, $p<0.001$, $\eta_p^2=0.33$). This is presented in Figure 14.



**p<0.01

Figure 14: Response Rates to traffic lights in different amber onset zones (mean values, error bars represent standard error)

Participants made significantly fewer responses to traffic lights when amber onset occurred in the safe crossing zone than when it occurred in the dilemma (MD=0.19, SE=0.03, $p<0.001$) or safe stopping zones (MD=0.17, SE=0.04, $p<0.001$). There was no significant difference in the number of lights responded to in the dilemma and safe stopping zones (MD=0.02, SE=0.03, $p=1.00$).

An analysis of covariance on response rate to traffic light events, including age as a covariate is presented in Table 10.

Table 10: Effects of experience group and amber onset zone on response rates to traffic lights in the Hazard Detection test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,34	0.16	0.70	0.01
Experience Group	1,34	1.07	0.31	0.03
Amber Onset Zone	2,33	1.81	0.17	0.05
AO Zone * Experience	2,33	0.94	0.40	0.03

Age did not have a significant effect on response rate to traffic light events ($F(1,34)=0.16$, $p=0.70$), and including age as a covariate did not affect the significance level of experience group ($F(1,34)=1.07$, $p=0.31$). However, the previously significant effect of amber onset zone disappeared when age was included ($F(2,33)=1.81$, $p=0.17$).

Response times to traffic lights with three different amber onset zones (safe stopping, dilemma, safe crossing) were averaged across speed zones. Missing values were replaced with the mean for each individual traffic light, leading to the replacement of 24.33% of the total responses. A two way between-within groups' analysis of variance was conducted to examine experience differences (between groups variable) and amber onset zone (within group variable) on response time to traffic lights. Results indicated that experience group did not have a significant effect on response time to traffic light events ($F(1,35)=0.89$, $p=0.35$, $\eta_p^2=0.03$), with novice drivers taking an average of 796ms (SE=44) and experienced drivers taking an average of 740ms (SE=38) to respond to traffic lights. There was also no significant effect of amber onset zone on response time to traffic lights ($F(2,34)=0.66$, $p=0.52$, $\eta_p^2=0.02$).

An analysis of covariance on response time to traffic events including age as a covariate is presented in Table 11.

Table 11: Effects of experience group and amber onset zone on response times to traffic lights in the Hazard Detection test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,34	2.77	0.11	0.08
Experience Group	1,34	3.34	0.08	0.09
Amber Onset Zone	2,33	1.04	0.36	0.03
AO Zone * Experience	2,33	0.74	0.48	0.02

Although the effect of age on response time does not reach significance ($F(1,34)=2.77$, $p=0.11$) a medium effect size of 0.08 suggests that more power may have led to an effect. When age is taken into account, the effect of experience group also approaches significance ($F(1,34)=3.34$, $p=0.08$). An analysis of the means shows that novice drivers (M=844ms, SE=52) took longer to respond to traffic lights than experienced drivers (M=703ms, SE=44), and the medium effect size of 0.09 suggests that this may be a meaningful difference. The inclusion of age in the model did not lead to any change in the significance of amber onset zone on response times ($F(2,33)=1.04$, $p=0.36$).

To summarize, it would appear that there was no differences between novice and experienced drivers response rates to traffic light events. However, when the effects of age were controlled for, there was a medium non-significant trend for novice drivers to respond more slowly to amber onset at traffic lights than experienced drivers. Participants made fewer lever press responses to amber-onsets occurring in the safe crossing zone than in the other zones. Since the safe crossing zone was designed to enable drivers to clear the intersection without changing their driving speed, this is a positive result indicating that participants had a good understanding of when a traffic light could constitute a hazard. However, this effect disappeared when age was included as a covariate in the model.

2.3.1.6 Summary of Results for Hazard Detection Test 1

Overall, these results suggest that, at least with the stimuli used in the current study, a simple discrete-response hazard perception test does not discriminate effectively between novice and experienced drivers in terms of detection rate or response time to either other road users or fixed elements of the environment. When age was taken into consideration, there was a trend for novice drivers to detect fewer hazards than experienced drivers. However, although this was a medium sized effect, it did not reach significance. There were no differences in the times taken by novice and experienced drivers to make a horn-press response to events they considered hazardous.

It would appear that participants make fewer responses to elements of the driving environment such as bends and traffic lights than to hazards involving other road vehicles and pedestrians. Participants responded more slowly to pedestrian events than to any other hazards. Further analysis suggests that this difference was due to the long response times to pedestrians with interrupted visibility. However, it is unclear as to whether this is a result of participants struggling to identify the interrupted visibility pedestrians as hazardous, or a result of these pedestrians being located further from the road when they start to move, thus allowing more time to respond.

A deeper analysis of traffic light events showed that there was no difference between novice and experienced drivers response rates to amber onset at traffic lights. However, when the effects of age were taken into account, there was a medium non-significant trend for novice drivers to respond more slowly to amber onset at traffic lights than experienced drivers. Participants responded to fewer amber-onsets occurring in the safe crossing zone than in the other zones. Since the safe crossing zone was designed to enable drivers to clear the intersection without changing their driving speed, this is a positive result indicating that participants had a good understanding of when a traffic light could constitute a hazard.

2.3.2 Hazard Handling Test

In the hazard handling condition, participants had full control of the simulator vehicle, and negotiated the same route as in the hazard detection study (the order of speed-zones differed). A response was taken to be a change in speed or directional control greater than 2SD over the duration of the hazard. Mixed between-within groups analysis of variance were conducted to compare the driving performance of novice and experienced drivers in response to each of the separate hazard types i.e. car emerging, merging traffic, pedestrians, traffic lights and bends. These analyses will be presented in the following sections.

2.3.2.1 Response Rate to Hazards

Response rate was measured by checking whether or not a change of 2SD in pedal/steering behaviour occurred from the point at which the hazard was triggered to the point at which the participant passed the hazard. Overall, a total of 95.28% of hazards were detected. A two-way mixed between-within groups analysis of variance was conducted to assess the impact of the between-group variable of experience group, and the within-group variable of hazard category (car emerging, merging traffic, pedestrian, traffic light, bend) on the response rate of hazards. The results are presented in Table 12.

Table 12: Effects of experience group and hazard category on response rates in the Hazard Handling test

	Df	F	p	η_p^2
Experience Group	1,36	0.58	0.45	0.02
Hazard Category	4,33	13.69	<0.001	0.28
Hazard Category * Experience	4,33	0.48	0.75	0.01

Experience group did not have a significant effect on the response rate to hazards ($F(1,36)=0.58$, $p=0.45$), with novice ($M=0.95$, $SE=0.01$) and experienced drivers ($M=0.96$, $SE=0.01$) detecting a similar number of hazards.

There was a large, significant effect of hazard category ($F(4,33)=13.69$, $p<0.001$, $\eta_p^2=0.28$) and this is presented in Figure 15.

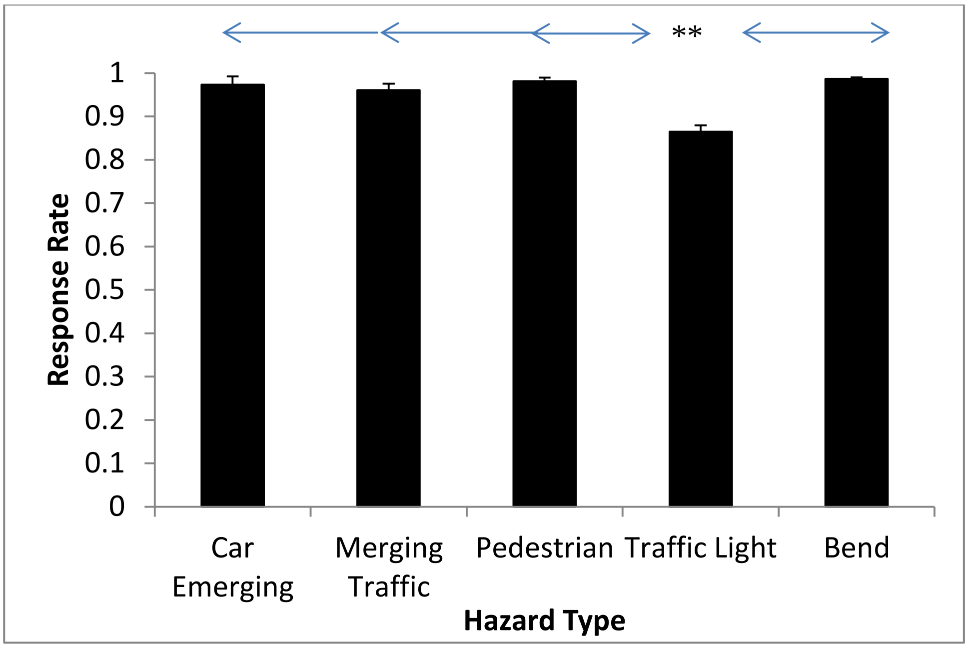


Figure 15: Response rates to individual hazard categories in the Hazard Handling test (mean values, error bars represent standard error)

A post-hoc Bonferroni comparison of means showed that only responses to traffic light hazards differed significantly from the rest ($p<0.01$). However there was still a very high detection rate of traffic light events ($M=0.87$, $SE=0.02$). As participants did not need to change their behaviour to safely clear the intersection when amber onset occurred in the safe crossing zone, this may provide an explanation for the lower response rate. This will be explored further in Section 2.3.2.4. When participants are driving themselves it appears almost all participants responded to all hazards presented. This leads to concern about the response criteria of 2SD, as it may be that a change in behaviour is being counted as a response when no conscious response was actually made. This will be explored further in Chapter 3.

In order to establish whether any experience effects were impacted by participant age, an analysis of covariance was also conducted to control for any age effects (see Table 13).

Table 13: Effects of experience group and hazard category on response rates in the Hazard Handling test, with age as a covariate

	Df	F	p	η_p^2
Age	1,35	<0.001	0.98	<0.001
Experience Group	1,35	0.29	0.60	0.01
Hazard Category	4,32	0.36	0.83	0.01
Hazard Category * Experience	4,32	0.55	0.70	0.02

Age did not have a significant effect on response rates to hazards while driving ($F(1,35)<0.001$, $p=0.98$), and controlling for the effects of age did not alter the effect of experience group ($F(1,35)=0.29$, $p=0.60$). However, when age is included in the model, the previously significant effect of hazard category disappears ($F(4,32)=0.36$, $p=0.83$).

The results indicate that there were no experience differences in the number of hazards responded to when participants were fully in control of the vehicle. Similar to the hazard detection test, participants responded to fewer traffic light hazards than to pedestrians, or other vehicles. However, unlike the hazard detection test, participants responded to a similar number of bends as other hazards.

2.3.2.2 Response Time to Hazards

Response times in the hazard handling test were calculated by measuring the time from which a hazard was triggered (i.e. started to move/light changed colour/curvature of bend began) to the point at which a change in driving behaviour of 2SD from the mean steering, accelerator or brake pressure occurred (see Section 2.2.3). Overall response latencies to each hazard category were computed by averaging across response times to each individual presentation of that hazard. Missing values were replaced by the mean for that particular variable, with a total of 4.5% of values being substituted.

Figure 16 shows the distribution of response times to all hazards presented in the hazard handling test.

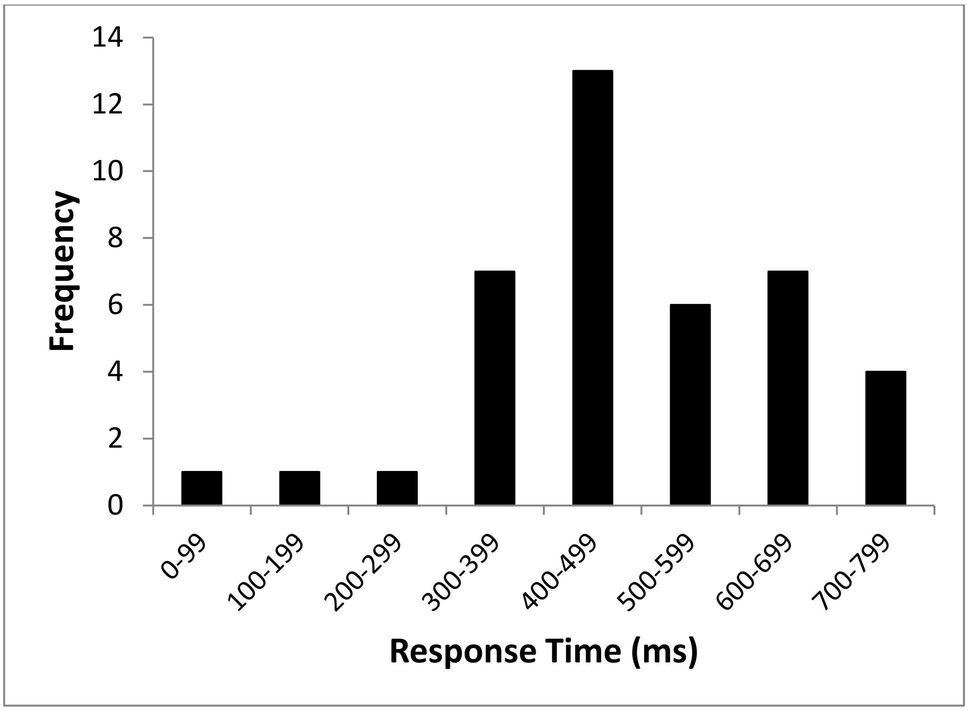


Figure 16: Distribution of response times in the Hazard Handling test

As can be seen in Figure 16, the distribution of response times appears relatively normal. A non-significant Kolmogorov-Smirnov statistic confirms this normality (Kolmogorov-Smirnov z(38)=0.55, p=0.92). Therefore, it was not necessary to transform the data prior to conducting further analysis.

A two-way mixed between-within groups analysis of variance was conducted to assess the impact of experience group (between-group) and hazard category (within-group) on the response time to hazards. The results are presented in Table 14.

Table 14: Effects of experience group and hazard category on response times in the Hazard Handling test

	Df	F	p	η_p^2
Experience Group	1,36	7.37	0.01	0.17
Hazard Category	4,33	59.74	<0.001	0.63
Hazard Category * Experience	4,33	1.12	0.31	0.03

There was a large significant effect of experience group on response time to hazards when driving ($F(1,36)=7.37$, $p<0.01$, $\eta_p^2=0.17$). As Figure 17 shows, experienced drivers (M=477ms, SE=26) responded more quickly to hazards than novice drivers (M=583ms, SE=29).

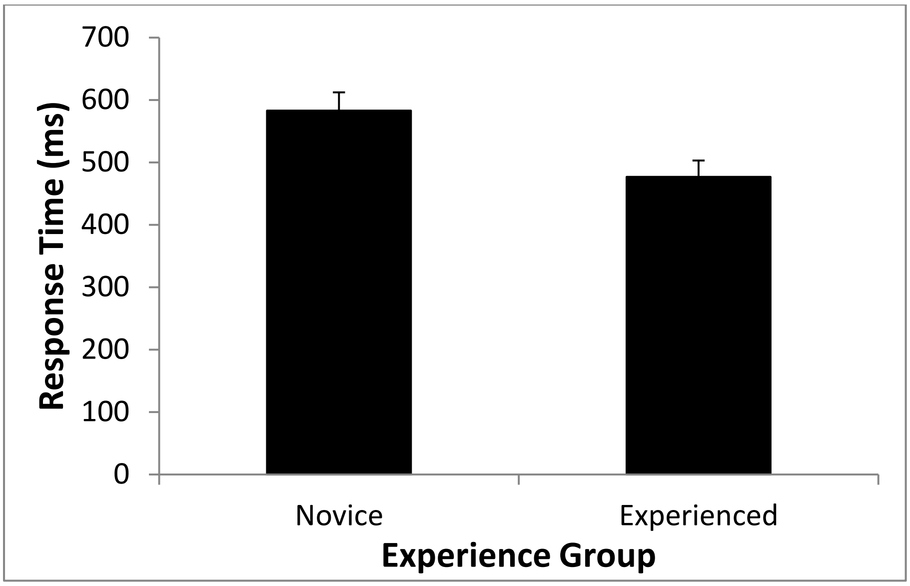


Figure 17: Comparing novice and experienced drivers response times in the Hazard Handling test (mean values, error bars represent standard error)

Hazard category also had a large significant effect on response time ($F(4,33)=59.74$, $p<0.001$, $\eta_p^2=0.63$). Figure 18 provides a breakdown of the response time to each individual hazard category.

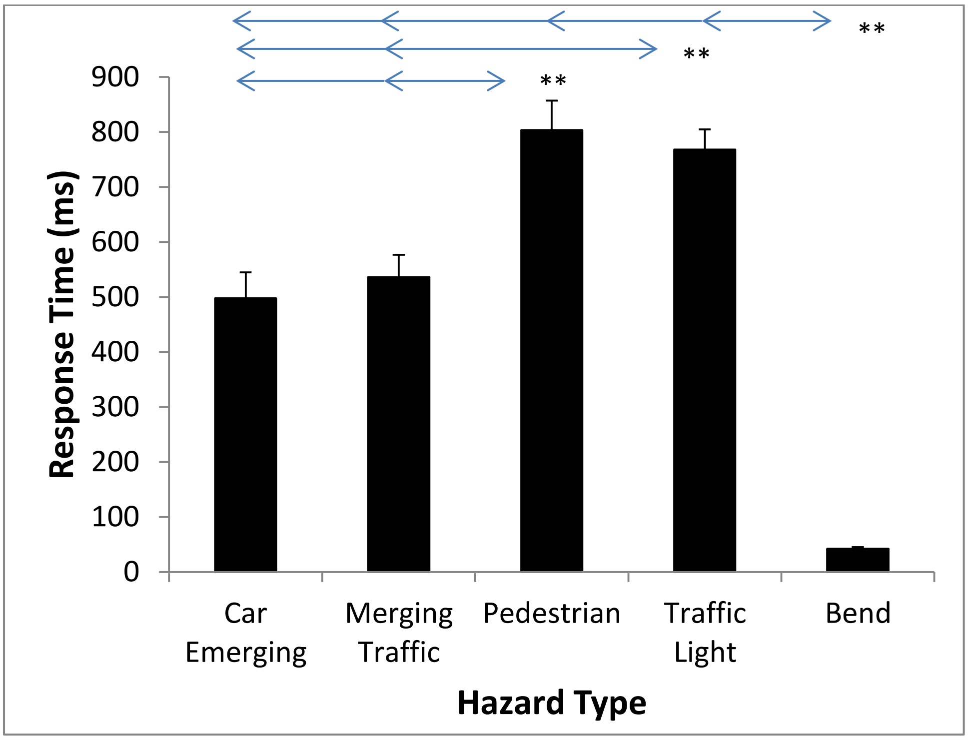


Figure 18: Response times to individual hazard categories in the Hazard Handling test (mean values, error bars represent standard error)

A post-hoc Bonferroni comparison of mean values showed that participants made significantly faster responses to bends than to all other hazards ($p<0.001$). Response times to car emerging and merging traffic hazards did not differ significantly from each other (MD=0.04, $p=1.00$), but did differ significantly from all other hazards ($p<0.01$). The slowest response times were to traffic light and pedestrian hazards, which did not differ significantly from one another (MD=0.04, $p=1.00$), but did differ significantly from all other hazards ($p<0.01$). This pattern of results is similar to that obtained in the hazard detection test, with the sole change being the lack of a significant difference between traffic light and pedestrian response times.

As with the hazard detection test, the longer response time to pedestrian events may be due to the fact that there were two levels to the pedestrian hazard (continuous and interrupted visibility) and this will be explored in greater detail in Section 3.3.2.3. The longer response times to traffic lights will also be explored further in Section 2.3.2.4.

In order to establish whether any experience effects were impacted by participant age, an analysis of covariance was also conducted to control for any age effects.

Table 15: Effects of experience group and hazard category on response times in the Hazard Handling test, with age as a covariate

	Df	F	p	η_p^2
Age	1,35	4.20	0.05	0.11
Experience Group	1,35	12.04	0.001	0.26
Hazard Category	4,32	0.44	0.78	0.01
Hazard Category * Experience	4,32	1.44	0.23	0.04

As Table 15 shows there was a medium, significant effect of age on response time to hazards while driving ($F(1,35)=4.20$, $p<0.05$, $\eta_p^2=0.11$). The significant effect of experience on response time remained, even when age effects were taken into account ($F(1,35)=12.04$, $p<0.001$), and in fact the difference between novice (M=623ms, SE=34) and experienced (M=445ms, SE=30) drivers was larger when age effects were removed ($\eta_p^2=0.26$ vs. 0.17). However, when the data was adjusted for age, the previously significant effect of hazard category on response time disappeared ($F(4,31)=0.44$, $p=0.78$, $\eta_p^2=0.01$).

The response time data indicate that when participants are driving themselves, experienced drivers respond significantly faster than novice drivers, regardless of their age. Although the effect disappeared when age was included in the model, the initial analysis showed that participants responded most slowly to traffic light changes and pedestrian events and these will be explored further in the following sections.

2.3.2.3 Example of Hazards Involving Other Road Users: Pedestrians with Continuous and Interrupted Visibility

As in the hazard detection test, there were two types of pedestrian hazard included in this study. Pedestrians with continuous visibility were fully visible at all times from when they started to move, whereas pedestrians with interrupted visibility disappeared behind a parked jeep for a period of one second before emerging onto the road (see Section 2.2.2.2.3).

Response frequency was averaged across the speed zones for pedestrians with continuous and interrupted visibility. Participants responded to a total of 97.85% of pedestrian events. A two-way mixed between-within subjects' analysis of variance evaluating the effects of experience groups (between-groups variable) and pedestrian visibility (within-groups variable) on response rates to pedestrians was conducted.
Results indicated that experience did not have a significant impact on the number of responses made to pedestrian hazards while driving ($F(1,36)=0.05$, $p=0.83$, $\eta_p^2=0.001$), with both groups making a similar number of responses ($M=0.98$, $SE=0.01$). High response rates suggested that the vast majority of pedestrians were detected, and that the detection rate was similar for continuous ($M=0.97$, $SE=0.02$) and interrupted visibility pedestrians ($M=0.99$, $SE=0.01$; $F(1,36)=1.96$, $p=0.17$, $\eta_p^2=0.05$).

In order to establish whether or not age had any influence on response rates to pedestrians, an analysis of covariance on response rate including age as a covariate is presented in Table 16.

Table 16: Effects of experience group and pedestrian visibility on response rates to pedestrian hazards in the Hazard Handling test, with age as a covariate

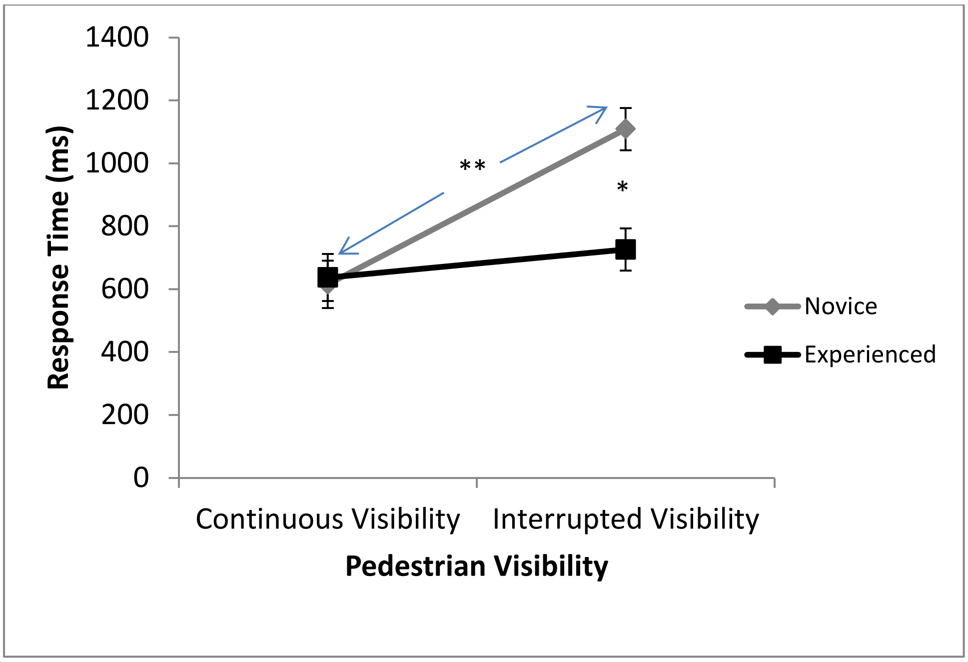
Pedestrians	Df	F	p	η_p^2
Age	1,35	0.10	0.75	0.003
Experience Group	1,35	0.14	0.71	0.004
Pedestrian Visibility	1,35	0.66	0.42	0.02
Visibility * Experience	1,35	1.06	0.31	0.03

The results show that age did not have a significant effect on response rate to pedestrian hazards ($F(1,35)=0.10$, $p=0.75$), and the inclusion of age in the model did not affect the significance levels of either experience group ($F(1,35)=0.14$, $p=0.71$) or pedestrian visibility ($F(1,35)=0.66$, $p=0.42$).

In order to further investigate response times to pedestrian events a two-way between-within groups' analysis of variance was conducted examining the effects of experience (between subjects) and the within-group variable of pedestrian visibility (continuous or interrupted) on response time. Missing values were replaced by the mean response time for each pedestrian variable, leading to the replacement of 2.15% of cases.

Experience group did not have a significant effect on response time to pedestrians while driving ($F(1,36)=3.17$, $p=0.08$). However, there was a trend for experienced drivers ($M=0.68$, $SE=0.07$) to respond more quickly to pedestrian hazards than novice drivers ($M=0.86$, $SE=0.08$), and a medium effect size of 0.08 suggests that this may be a meaningful difference.

There was a significant effect of visibility level on response time to pedestrian hazards ($F(1,36)=7.86$, $p<0.01$, $\eta_p^2=0.18$) with participants responding significantly more quickly to pedestrians with continuous visibility ($M=0.63$, $SE=0.05$) than pedestrians with interrupted visibility ($M=0.92$, $SE=0.09$). In addition, the interaction between visibility level and experience group approached significance ($F(1,36)=3.76$, $p=0.06$) and the medium effect size of 0.10 suggests this merits further examination.



*p<0.05, **p<0.01

Figure 19: Interaction between pedestrian visibility and experience group on response times in the Hazard Handling test (error bars represent standard error)

Independent and paired samples t-tests were conducted to investigate the relationships presented in Figure 19. Novice participants (M=1109ms, SE=130) responded significantly more slowly to pedestrians with interrupted visibility than experienced drivers (M=726, SE=120; $t(36)=2.13$, $p<0.05$, $|d|=3.02$). There was no significant difference between the groups in response time to pedestrians with continuous visibility ($t(36)=-0.21$, $p=0.84$, $d=0.06$).

In order to establish the independent effects of age and experience on response times to pedestrian hazards, a two way between-within subjects analysis of covariance was conducted to control for age (see Table 17).

Table 17: Effects of experience group and pedestrian visibility on response times to pedestrian hazards in the Hazard Handling test, with age as a covariate

Pedestrians	Df	F	p	η_p^2
Age	1,35	1.84	0.18	0.05
Experience Group	1,35	5.03	0.03	0.13
Visibility	1,35	0.18	0.67	0.01
Visibility * Experience	1,35	1.92	0.18	0.05

The results show that there was no significant effect of age on response rate to pedestrian hazards ($F(1,35)=1.84$, $p=0.18$). Experience group became a significant predictor of response time performance when the effects of age were accounted for ($F(1,35)=5.03$, $p<0.05$, $\eta_p^2=0.13$), with novice drivers (M=932ms, SE=91) taking longer to respond to pedestrians than experienced drivers (M=625ms, SE=79). However, when age is included in the model the previously significant effect of pedestrian visibility ($F(1,35)=0.18$, $p=0.67$) and the interaction between visibility and experience group ($F(1,35)=1.92$, $p=0.18$) disappeared.

The results suggest that experience is a predictor of the speed at which participants recognise pedestrian hazards, and this appears to occur especially in relation to pedestrians who are hidden for a period of time. However, it is not clear whether novices slower response times to pedestrians with interrupted visibility was due to the fact that they were hidden for a period of time, or due to the fact that they started to move earlier and thus novice drivers may have felt that they had a longer time-frame in which to select a response.

2.3.2.4 Example of Hazards Involving Elements of the Traffic Environment: Traffic Light Events

This section will provide a further exploration of traffic light events to provide more insight into drivers' response patterns to fixed objects in the driving environment. Results from the hazard handling test show that responses to traffic lights differed significantly from responses to other hazards, with participants responding to fewer amber-onsets at traffic lights than to any other hazard. There were three levels of traffic light zone; safe stopping zone, dilemma zone, and safe crossing zone (see Section 2.2.2.2.4). Responses to traffic light events were averaged across speed-zones and two-way between-within groups analysis of variance were conducted on the response rate and response time to traffic light events.

Overall, drivers changed their behaviour in relation to 86.23% of amber-onsets at traffic lights. An analysis of variance examining the effect of experience (between-groups variable) and amber onset zone (within-group variable) on response frequency found that experience did not have a significant effect on response rates to traffic light hazards ($F(1,36)=0.10$; $p=0.75$, $\eta_p^2<0.01$), with novice and experienced drivers making a similar number of responses (M=0.86, SE=0.02).

There was a medium significant effect of amber onset zone on detection rate ($F(2,35)=4.14$; $p<0.001$, $\eta_p^2=0.10$) and this is displayed in Figure 20 below.

**p<0.01

Figure 20: Response rates to traffic lights in different amber onset zones (mean values, error bars represent standard error)

Participants responded to significantly more amber-onsets in the dilemma zone (M=0.93, SE=0.02) than in either the safe stopping (MD=0.10, SE=.03, p<0.01) or safe crossing zones (MD=0.09, SE=.03, p<0.05). In the hazard detection test participants had responded to significantly fewer amber onsets in the safe crossing zone than in the other two zones. The changed results when participants are actually driving themselves may be an indication that drivers change their behaviour at most traffic lights, but particularly ones in which the correct decision is not clear, as in the dilemma zone.

In order to further break down the influence of age and experience on response rate to traffic lights, a between-within groups analysis of covariance was conducted to control for the effects of age (see Table 18).

Table 18: Effects of experience group and amber onset zone on response rates to traffic lights in the Hazard Handling test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,35	0.72	0.40	0.02
Experience Group	1,35	0.12	0.73	0.003
Amber Onset	2,34	0.26	0.77	0.01
AO Zone * Experience	2,34	0.32	0.73	0.01

Age did not have a significant effect on response rates to traffic light events ($F(1,35)=0.72$, $p=0.40$), nor did the inclusion of age lead to any change in the effects of experience group on response rate ($F(1,35)=0.12$, $p=0.73$). However, when age was included in the model, the previously significant effect of amber-onset zone disappeared ($F(2,34)=0.26$, $p=0.77$).

A two-way between-within groups' analysis of variance was also conducted to evaluate the effect of experience group (between group) and amber onset zone (within group) on response time to traffic lights. Missing values were replaced with the mean response time for each individual hazard, leading to the replacement of 13.77% of responses. Results indicated that experience group did not have a significant effect on response times ($F(1,36)=0.05$, $p=0.82$, $\eta_p^2<0.01$), with novice (M=780ms, SE=50) and experienced drivers (M=760ms, SE=40) taking a similar length of time to respond to traffic lights.

There was a large significant effect of amber onset zone on response time ($F(2,35)=7.52$, $p<0.01$, $\eta_p^2=0.17$). This is displayed in Figure 21.

Figure 21: Response times to traffic lights in different amber-onset zones (mean values, error bars represent standard error)

Participants responded significantly more slowly when they were in the safe stopping zone than when they were in the safe crossing (MD=200ms, SE=80, p<0.05) or dilemma zones (MD=280ms, SE=70, p<0.001). There was no significant difference in response time to safe crossing and dilemma zones (MD=80ms, SE=80, p=0.89). As participants were furthest away from the traffic lights when amber onset occurred in the safe stopping zone, and thus had more time in which to make a response, this result is not surprising.

In order to explore the findings around traffic lights further, a between-within groups analysis of covariance was conducted, with age as a covariate (see Table 19).

Table 19: Effects of experience group and amber onset zone on response times to traffic lights in the Hazard Handling test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,35	1.34	0.25	0.04
Experience Group	1,35	0.93	0.34	0.03
Amber Onset	2,34	0.16	0.85	0.01
AO Zone * Experience	2,34	0.24	0.79	0.01

Age did not have a significant effect on response rates to traffic light events (F(1,35)=1.34, p=0.25), and including age did not lead to any effects of experience group on response rate emerging ($F(1,35)=0.93$, $p=0.34$). However, when age was included in the model, the previously significant effect of amber-onset zone disappeared ($F(2,34)=0.16$, $p=0.85$).

The results involving traffic light events show that there were no differences between novice and experienced drivers in their responses to these fixed elements of the driving environment. Initial analyses showed that participants responded to the majority of traffic lights in all three amber-onset zones, but were particularly likely to change their behaviour by more than 2SD when in the dilemma zone. In addition, they took significantly longer to change their behaviour in relation to traffic lights in the safe stopping zone. However, both of these results disappeared when age was included in the model.

2.3.2.5 Summary of Results of Hazard Handling Test

Overall, the hazard handling test based on actual driving behaviour appears to successfully discriminate between novice and experienced drivers response time to hazards. When participants are driving themselves, experienced drivers respond significantly faster than novice drivers, regardless of their age. There was a very high response rate to almost all of the hazards and this may indicate an inclusion of false alarms which might obscure experience-related differences in hazard detection. This will be further explored in Chapter 3.

As in the hazard detection test, there appears to be a significant difference in how the hazardousness of various traffic events are evaluated by drivers, with participants responding to significantly fewer traffic light events than any other type of hazard. A closer examination of these events shows that the difference is a result of lower response times to traffic lights with amber onset in the safe stopping and safe crossing zone. It is possible that changes in these zones did not all reach 2SD from mean behaviour, as participants could gradually change their behaviours and still make a safe response in these zones.

In terms of response time, it is clear from the results that participants took significantly longer to respond to pedestrian hazards than to any other hazard type, particularly those who were temporarily hidden, with this effect being substantially more pronounced in the case of novice drivers. However, this effect is potentially confounded by the fact that the interrupted visibility pedestrians started to move earlier than the pedestrians with continuous visibility, leaving participants with a longer time-frame within which to act. Participants took significantly longer to change their behaviour in relation to traffic lights in which amber onset occurred in the safe stopping zone rather than the dilemma or safe crossing zones. However, both of these results disappeared when age was included in the model. Finally, it appeared that participants had much faster response times to bends than to any of the other hazards. This may be an indication that drivers' change their behaviour with regard to bends on the road before they actually reach the curved centre of the bend.

Finally, the results show the relationship between experience and response time to hazardous events can change as a result of age. This highlights the importance of taking both variables into account in any analysis of experience-related differences in hazard responses.

2.3.3 Comparing Hazard Detection and Hazard Handling

In order to evaluate the difference between the more traditional style hazard detection test and a more ecologically valid hazard handling test, a mixed between-within groups analysis of variance was conducted to comparing the overall response frequency of novice and experienced drivers (between-groups) across tests (within-groups; see Table 20).

Table 20: Comparing response rates in the Hazard Detection and Hazard Handling tests

Comparison of Tests	Df	F	p	η_p^2
Experience Group	1,36	4.40	0.04	0.11
Hazard Test	1,36	100.57	<0.001	0.74
Hazard Test * Experience	1,36	1.07	0.31	0.03

There was a medium, significant experience effect on overall response rate to hazards ($F(1,36)=4.40$, $p<0.05$, $\eta_p^2=0.11$), with experienced drivers ($M=0.89$, $SE=0.01$) responding to more hazards than novice drivers ($M=0.86$, $SE=0.01$) across the two tests. There was also a large significant effect of test type on response rate ($F(1,36)=100.57$, $p<0.001$, $\eta_p^2=0.74$), with participants detecting significantly more hazards in the hazard handling test (M=0.95, SE=0.01) than in the hazard detection test (M=0.79, SE=0.02; see Figure 22).

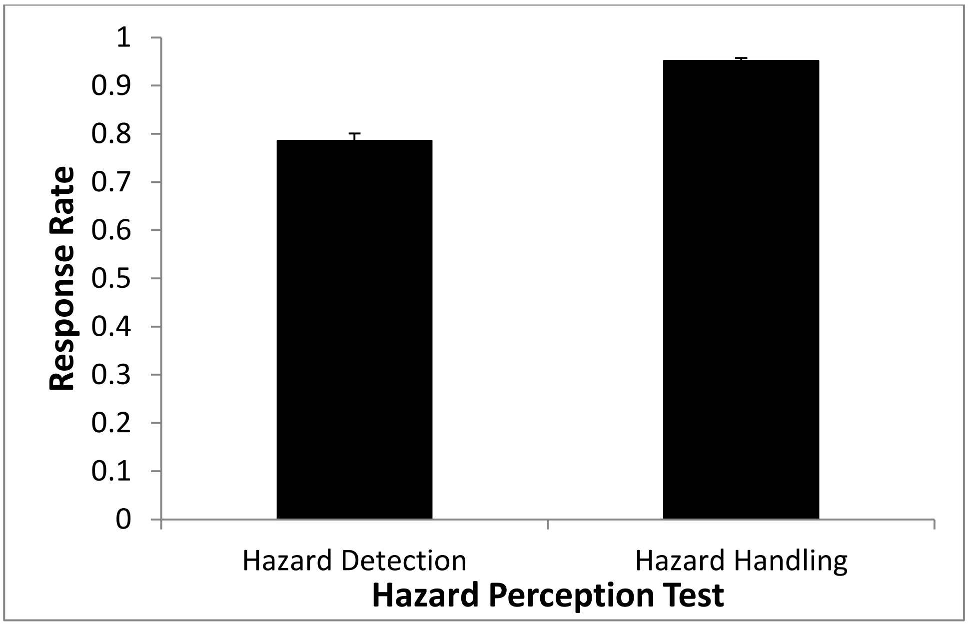


Figure 22: Comparison of response rates in Hazard Detection and Hazard Handling tests (mean values, error bars represent standard error)

When age was included as a covariate (see Table 21), results remained similar in terms of the effect of experience on response rate ($F(1,35)=6.53$, $p=0.02$, $\eta_p^2=0.16$). However, the previously significant effect of test type disappeared when age was included ($F(1,35)=0.08$, $p=0.77$).

Table 21: Comparing response rates in the Hazard Detection and Hazard Handling tests, with age as a covariate

Comparison of Tests	Df	F	p	η_p^2
Age	1,35	2.09	0.16	0.06
Experience Group	1,35	6.53	0.02	0.16
Hazard Test	1,35	0.08	0.77	0.002
Hazard Test * Experience	1,35	2.59	0.12	0.07

A mixed between-within groups' analysis of variance was also conducted to compare experienced and novice drivers overall response times to hazardous events in the hazard detection and hazard handling tests (see Table 22).

Table 22: Comparing response times in the Hazard Detection and Hazard Handling tests

Comparison of Tests	Df	F	p	η_p^2
Experience Group	1,36	4.80	0.04	0.12
Hazard Test	1,36	95.35	<0.001	0.73
Hazard Test * Experience	1,36	0.77	0.39	0.02

The effect of experience group was significant ($F(1,36)=4.80$, $p<0.05$, $\eta_p^2=0.12$) with novice drivers (M=698ms, SE=28) taking longer to respond to hazards than experienced drivers (M=615ms, SE=25) across the two tests. There was a large effect of type of test on response time ($F(1,36)=95.35$, $p<0.001$, $\eta_p^2=0.73$), with participants exhibiting much faster response times in the hazard handling test (M=530ms, SE=30) than in the hazard detection test (M=790ms, SE=26; see Figure 23).

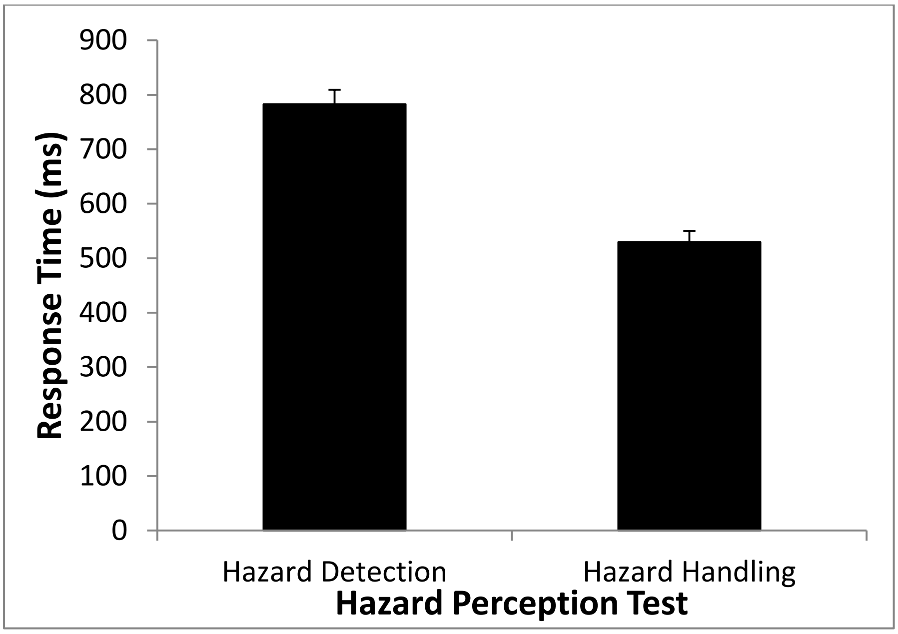


Figure 23: Comparison of response times in Hazard Detection and Hazard Handling tests (mean values, error bars represent standard error)

The results did not alter when age was included as a covariate (see Table 23).

Table 23: Comparing response times to hazards in the Hazard Detection and Hazard Handling tests, with age as a covariate

Comparison of Tests	Df	F	p	η_p^2
Age	1,35	1.88	0.18	0.05
Experience Group	1,35	6.53	0.02	0.16
Hazard Test	1,35	5.78	0.02	0.14
Hazard Test * Experience	1,35	1.71	0.20	0.05

Age did not have a significant effect on response times to hazards across the two tests ($F(1,35)=1.88$, $p=0.18$). The effect of experience group remained significant ($F(1,35)=6.53$, $p<0.05$, $\eta_p^2=0.16$), indicating that experience has an effect on response time above and beyond that of age alone. Finally, the significant effect of hazard test remained when age was included in the model ($F(1,35)=5.78$, $p<0.05$, $\eta_p^2=0.14$).

2.3.3.1 Summary

It appears that participants made more responses to hazards when driving in the hazard handling test, than when actively attempting to detect them in the hazard detection test. Interestingly, participants also responded significantly more quickly to hazardous events when driving themselves than when solely focused on identifying hazards. This will be discussed further in the next section.

2.4 Discussion

This study provided a description of two types of hazard perception test, both of which took place in an immersive driving environment. The hazard detection test was based on previous hazard perception tests which required a button press response to hazards presented on a computer screen. However, this study differed from previous research as it was the first study to require participants to make discrete responses to hazards presented in a more fully immersive environment. The hazard handling test monitored participants' actual driving behaviour when dealing with the same hazards in a more naturalistic driving situation.

2.4.1 Hazard Detection and Hazard Handling

Overall, the results suggest that the simple discrete-response hazard detection test used in this study does not discriminate effectively between novice and experienced drivers in terms of detection rate or response time to either other road users or fixed elements of the environment. When age was taken into consideration, the difference between the response rates of novice and experienced drivers approached significance, with experienced drivers detecting a greater number of hazardous events than novice drivers. This was a medium sized effect suggesting that with greater power this may have been an appreciable effect. There were no differences in the times taken by novice and experienced drivers to make a horn-press response to events they considered hazardous.

The hazard handling test measuring participants driving responses to hazards, appears to successfully discriminate between novice and experienced drivers response times. Experienced drivers responded significantly faster than novice drivers, and this effect existed independently of any age effects. There were no experience-related differences in the number of hazards responses made, suggesting the possibility that novice drivers are equally as good as experienced drivers at identifying hazards but are not as fast at processing this information, or less capable of selecting appropriate action once a potential hazard is identified. Huestegge et al. (2010) had similar results using static images, showing that there were no differences between novice and experienced drivers in the time until initial fixation on hazards presented in a static scene. However, experienced drivers had faster button press responses to these hazards, suggesting that the difference in hazard perception skill arose in how quickly people can process hazard responses. In Chapter 1, a detailed outline of Groeger’s (2000) Cognitive Account of Driving was provided. This model suggests that the processes of hazard detection and action selection/implementation take place separately. The findings of this study provide initial evidence that this is the case, and highlights the importance of separating out the processing of detecting and responding to hazardous events. It should be noted that there was a very high response rate to almost all of the hazards in the current study, and this may indicate an inclusion of false alarms which might obscure experiences in hazard detection.

Groeger's (2000) model defines the process of risk assessment as consisting of four steps of hazard detection, threat appraisal, action selection, and implementation. This model suggests that hazard detection should precede action implementation in the process of responding to hazards. In the current study, the hazard handling condition required drivers to detect a hazard, select an appropriate response, and implement that response; whereas the hazard detection condition cut out the middle step. However, the results of this study show that participants actually had faster response times in the hazard handling condition than in the hazard detection condition. This suggests that the more naturalistic circumstances of the hazard handling test made it easier for participants to respond quickly than the more artificial, un-practiced action of pressing the horn in the hazard detection test.

2.4.2 Individual Hazard Categories

Although many studies have examined the concept of response time to hazards presented on a screen, few have focused on the specific types of hazard which discriminate effectively between novice and experienced drivers (Crundall et al., 2012). This study aimed to address this issue by looking at the specific types of events included in the hazard perception test. These hazards were separated into unexpected obstacles, where the actions of other road users cause a hazardous situation to arise (i.e. car emerging, merging traffic, and pedestrian hazards); and environmental hazards which refer to fixed elements of the traffic environment (bends and traffic lights). Groeger's (2000) model suggests that responses to hazardous events will vary as a result of the level of threat appraised. This suggests that participants will respond differently depending both on how early they perceive a hazard and on how dangerous they think that hazard is. In order to investigate this further, a focused investigation was carried out on two different types of hazard, namely pedestrians and traffic lights.

There were two types of pedestrian events, continuous visibility pedestrians and interrupted visibility pedestrians. The pedestrians with interrupted visibility were designed to be high-demand as they required the participant to search quite far ahead on the roadway to see the initial pedestrian movement. In addition it required participants to understand that a large parked vehicle could be obscuring a hidden hazard. The pedestrians with continuous visibility were lower demand hazards as they could be clearly seen from the moment at which their movement began. In the hazard detection test, participants responded most quickly to bends and most slowly to traffic light and pedestrian events. Analysis of pedestrian hazards suggests the long response time to these hazards was due to driver's slow responses to pedestrians with interrupted visibility. However, it is unclear as to whether this is a result of participants struggling to identify the interrupted visibility pedestrians as hazardous, or a result of these pedestrians being located further from the road when they start to move, thus allowing more time to respond. There were no differences between the experience groups in the number of pedestrians identified as hazardous, or the time taken to identify these pedestrians. In the hazard handling test, there appears to be significant differences in how the hazardousness or threat of various traffic events was evaluated by drivers. Participants took significantly longer to respond to pedestrian hazards in the hazard handling condition than to any other hazard type. A deeper analysis found that this was due to slower response time, particularly by novice drivers, to pedestrians who were temporarily hidden. It appears that experienced drivers changed their behaviour as soon as they saw any pedestrian move, but that novice drivers took longer to respond to pedestrians whose movements were partially obscured. What is not clear is whether this was due to novice drivers taking longer to identify these pedestrians as hazardous (i.e. hazard detection), or whether the fact that these pedestrians started to move earlier led novice drivers to believe they had a longer time-frame to work with (i.e. threat appraisal/action selection). Both tests showed that the level of pedestrian visibility (or movement time) led to differences in participants' speed of detection. However, only the hazard handling test was able to discriminate between novice and experienced drivers performance on this hazard suggesting that a monitoring of action implementation provides a more sensitive measure of hazard reaction ability.

A deeper analysis of traffic light events showed that there was no difference between novice and experienced drivers response rates to amber onset at traffic lights in the hazard detection condition. When the effects of age were taken into account, there was a medium non-significant experience effect indicating that novice drivers responded to fewer amber onsets at traffic lights than experienced drivers. Participants also responded to fewer amber-onsets occurring in the safe crossing zone than in the other zones. Since the safe crossing zone was designed to enable drivers to clear the intersection without changing their driving speed, this is a positive result indicating that participants had a good understanding of when a traffic light could constitute a hazard. There was no difference in response times across amber-onset zones. In the hazard handling test, participants responded to significantly fewer traffic light events than any other type of hazard. A closer examination of these events shows that the difference is a result of participants making fewer responses to amber onsets in the safe stopping and safe crossing zone. As these zones were designed to enable participants to comfortably stop or go based on the speed limit, it is possible that any changes in driving behaviour in these zones did not all reach the change criterion, as participants could gradually change their behaviours and still make a safe response in these zones. Participants took significantly longer to change their behaviour in relation to traffic lights when amber onset occurred in the safe stopping zone rather than the dilemma or safe crossing zones. As participants were further away from the traffic lights at amber onset in this zone than the other zones, this difference is most likely due to drivers feeling they had more time to react. These results provide evidence that there is an appraisal process involved in the decision of whether or not to change driving behaviour in relation to potentially hazardous situations. The hazard handling condition allows a more nuanced understanding of why/when traffic lights might be perceived as more/less hazardous.

Unexpectedly, both the traffic light and pedestrian effects disappeared when age was included in the model. This highlights the importance of taking into account both the influence of age and experience on responses to hazardous events.

2.4.3 Limitations

There were a number of design issues with the hazard tests used in this study. Firstly, some of the hazards in the 25kph speed-zone consistently failed to trigger properly (the medium and large bends in the interrupted visibility condition of the bend hazards; the dilemma zone traffic light, the car emerging event). In addition, there was a potential confounding of preview time and hazard features, as the preview time for the pedestrian hazards varied across visibility levels (continuous and interrupted). Furthermore, participants had an extremely high response rate to hazards presented in the hazard handling condition. This high response rate brings up the possibility that the response criterion was not strict enough, and that some of the responses included may have been false alarms.

These issues provide some concern as to the reliability of the results emerging in this Chapter, thus they will be tackled in Chapter 3 in an effort to improve the quality of the hazard perception drives.

2.4.4 Summary and Conclusions

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Novice drivers will signal the presence of hazards more slowly than experienced drivers in an immersive simulated environment
- Hypothesis 2: Novice drivers will respond more slowly than experienced drivers in a hazard handling test, which requires drivers to change their actual driving behaviour in response to hazards.
- Hypothesis 3: The benefits of experience will vary across hazards, providing a better understanding of the threat appraisal process in hazard responding.

The results presented show that Hypothesis 1 cannot be supported as there was no significant response time difference between novice and experienced drivers in the hazard detection test. However, novice drivers are slower to implement hazard reactions when actually driving themselves, thus providing support for Hypothesis 2. This suggests that any difference between novice and experienced drivers hazard reaction ability is a result of how quickly they can process hazard responses.

Previous research had failed to consider why specific hazards might discriminate between novice and experienced drivers. A thorough analysis focusing on pedestrian and traffic light hazards suggests that participants respond more/less quickly to hazardous situations depending on the specific features of that situation. This highlights the importance of taking into consideration the threat inherent in a particular situation, based on the specific characteristics of a hazardous event (e.g. pedestrian with continuous or interrupted visibility).

3 Chapter 3: Driving Theory, Hazard Detection and Hazard Handling

3.1 Introduction

Chapter 2 provided an outline of the results of two studies designed to evaluate the process of perceiving and responding to hazardous situations using Groeger's (2000) Cognitive Account of Driving. The focus in this chapter is on replicating the previous experience-related differences obtained, along with investigating the relationship between the knowledge of the theory of driving and hazard perception skills.

3.1.1 Skill Acquisition in Driving

Anderson (1982) in his Adaptive Control of Thought (ACT) model separates the process of skill acquisition into three main stages: declarative, knowledge compilation and procedural. Declarative knowledge consists of factual information about the processes involved in a given activity. It is explicit information, in that a person can report it. It provides a semantic network of facts about items within a domain, which the learner must put together with general problem-solving strategies to perform tasks within the domain (Groeger, 2000). Productions i.e. condition-action rules are formed on the basis of the outcomes of the application of declarative strategies in different circumstances. These productions are different from declarative knowledge in that the production is committed to a specific goal (Anderson, 1992; Anderson, Matessa, & Lebiere, 1997). In the knowledge compilation stage, sequences of productions that follow each other in solving a particular problem are condensed into a single production. This is known as composition. This process serves to speed up the action process, as there is no longer any need to think though the various steps involved in task production (Anderson, 1982). The outcome of repeated use of the same production is known as proceduralisation. Skilled behaviour is seen as procedural in nature, and is often implicit, revealed in outcomes rather than conscious awareness of the routines themselves (Anderson et al., 1997). In Anderson's initial model, it was claimed that all knowledge first came into the system in declarative form, but the most recent version of the ACT-R (Adaptive Control of Thought – Rational) claims that most learning involves the acquisition of both types of skill. However, some declarative knowledge must be acquired before proceduralisation is possible (Anderson & Fincham, 1994). Anderson's model predicts that learners will benefit from on-going instruction and feedback on performance, by enhancing the declarative knowledge available to the learner and directing the learner's attention to those aspects of the task that are important. However, the theory does not predict that classroom-based education will be an effective means of learning to drive, and any effect of such education would be expected to diminish as the learner gains experience of actually performing the task (Groeger & Banks, 2007).

As a skill becomes more practised, it becomes automatic and thus, interferes less with a concurrent task, and is less interfered with by a concurrent task (Anderson, 1992). A number of studies have investigated the idea that driving is an automatic task, and therefore that once a driver gains sufficient experience, full proceduralisation will have taken place (McKenna & Crick, 1997). These studies have failed to find any evidence that this is the case. Strayer and colleagues have conducted in-depth analyses of mobile phone use while driving (Strayer & Drews, 2004, 2007). In a series of driving simulator studies they have found that the use of a mobile phone or a hands free kit while driving led to slower response times, greater following distances and a two-fold increase in the number of rear-end collisions. Lansdown, Brook-Carter, and Kersloot (2004) used a driving simulator to examine interference effects on driving. In their experiment, participants were initially asked to drive as they normally would until a number was presented on the left screen, after which they were told to press a particular key to dismiss the number depending on whether it was odd or even. A separate group of participants were told to press a key to dismiss a letter appearing on the right screen depending on whether it was a vowel or a consonant. Both of these tasks occurred simultaneously with the driving task. Results indicated that participants maintained a shorter headway when completing the secondary tasks than a control group who completed no secondary task. Participants also maintained a higher speed in the control task than in the secondary tasks. The introduction of either secondary task led to detriments in performance, but the introduction of both the letter and number task at the same time led to the greatest detriments in performance, indicating that simultaneous interaction with multiple secondary tasks leads to increased mental workload and further degradations in performance than one secondary task alone. These studies provide evidence that even experienced drivers have not adopted a fully proceduralised/automatic ability to complete all of the tasks involved in driving, as dual task studies show evidence of distraction effects across a number of spectrums.

Groeger and Clegg (2007) have found that a power law relationship exists between amount of driving practice and driving instructors' comments to pupils, with the frequency of comments declining in a systematic manner across the training. This decrease in comments reflected the number of times the manoeuvres were repeated, not just the time spent behind the wheel, suggesting that some aspects of driving skill are acquired faster than others e.g. simple manoeuvring tasks such as moving off or stopping. This research suggests that although some elements of driving may become proceduralised relatively quickly, other elements of the task will take longer to become automatic, and may never do so. Interestingly, an earlier study showed that the one area of driving training where instructor comments do not decrease in a power function is where comments were concerned with appreciation of risk and likely behaviour of other drivers (Groeger, 2001). However, the terms 'risk', 'danger' and 'hazard' comprised only two per cent of all instruction given, suggesting that learner drivers are not receiving an opportunity to improve their hazard perception skills, and thus are not developing procedural knowledge regarding hazardous elements in the environment.

Although the effects of distraction have rarely been examined in relation to hazard perception skill, a few studies have looked at the effects of a secondary task. McKenna and Crick (1997) argued that if driving was an automatic task, with practice it would become relatively undemanding, allowing the driver to carry out other tasks without interference. They liken hazard perception skill to running a simulation, claiming that drivers are actively involved in constructing and running a predictive model, thus the task is not automatic. To test this, they conducted a study whereby drivers had to listen to a continuous sequence of speech and make appropriate responses while at the same time completing a hazard perception test involving button press responses to hazards presented on a screen. It was found that the secondary task led to interference in the time taken to detect hazards. This supports the notion that the detection of hazards is not an automatic process, and requires declarative processing of the driving situation.

3.1.2 Driving Theory

In Ireland, all prospective drivers must pass a Driver Theory Test (DTT) prior to receiving their provisional driving license. This has been in place since 2001 and is designed to test participants knowledge of general road safety and motoring legislation, covering areas such as the rules of the road, risk perception, hazard awareness and good driving behaviour (D.T.T., 2013). The test is computer based, with a multiple choice design, where participants are asked to use a mouse to select the correct answer out of four possible answers displayed on screen. In order to pass, participants must answer a minimum of 35 out of 40 questions correctly.

It can be assumed that this test taps into the declarative knowledge about driving as it is assessing people’s explicit knowledge about the skills involved in driving. Although it would seem intuitive that knowledge of driving would help improve driving skill, research has found little benefit of classroom based driver education (Mayhew, 2007), and there may not be a strong link between declarative knowledge of the rules of the road and the ability to perceive and respond to hazards in the environment. This study will evaluate the relationship between performance on the driver theory test, which includes questions designed to measure hazard perception skill, and performance on the hazard detection and hazard handling tests. This will allow a deeper understanding of the relationship between the declarative knowledge of driving rules and procedures, and more procedural knowledge necessary for hazard responding while driving.

3.1.3 Hazard Detection and Hazard Handling Tests

The results presented in Chapter 2 showed that experienced drivers responded more quickly to hazards when a response was taken as a change in driving behaviour rather than a lever press. The results also provide some initial evidence for separating out the processes of hazard detection and hazard handling (action selection & implementation) as discussed by Groeger’s (2000) Cognitive Account of Driver Behaviour. Finally, the results show the importance of looking at the individual features of driving events to better understand the appraisal of threat in a situation.

However, there were a number of design issues with the hazard tests used in the first study (see Section 2.4.3 for more detail). In order to tackle these issues a new set of hazards were developed. A number of participants had found that the 25kph zone took too long in the first study and as there were difficulties in triggering the variables in the 25kph zone, the majority of hazards from this speed-zone were excluded, with only the 25kph bends remaining. The trigger times for the behavioural hazards were standardised across all the speed-zones and there was one of each hazard in each speed-zone (40kph, 60kph, 70kph, 100kph) to control for any speed effects.

This study also differs from those in Chapter 2 through the inclusion of control variables. These variables were designed to allow an evaluation of false alarms. The control variables initially looked the same as the hazard variables but they did not move at any stage. Behaviour was measured for the same length of time around the control variable as for the corresponding hazard event. The number and timings of any responses across the two variable types were then compared.

Finally, the results outlined in Chapter 2 show the difficulties in separating out the effects of age and experience on hazard perception. The inclusion of age in driving models of hazard perception allows an evaluation of what experience effects, if any, occur regardless of participant age. Therefore, all of the results outlined in this chapter will include age as a covariate.

3.1.4 Study Aim and Research Questions

The initial purpose of the studies in this chapter is to replicate the experienced-novice driver difference which emerged in Chapter 2, using a more tightly controlled hazard drive. Once again, the impact of individual hazard variables, particularly pedestrian and traffic lights, will be explored. Finally, the relationship between knowledge of the theory of driving and performance on hazard detection and hazard handling tests will be compared to investigate the nature of the learning being assessed by each test.

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Novice drivers will signal the presence of hazards more slowly than experienced drivers in an immersive simulated environment

- Hypothesis 2: Novice drivers will respond more slowly than experienced drivers in a hazard handling test, which requires drivers to change their actual driving behaviour in response to hazards.
- Hypothesis 3: The benefits of experience will vary across hazards, providing a better understanding of the threat appraisal process in hazard responding. Based on the results emerging in Chapter 2, it is anticipated that hazards involving other road users (pedestrians, car emerging, and merging traffic events) will provide better discrimination than hazards involving elements of the environment (bends, traffic lights).
- Hypothesis 4: Participants will make fewer responses to control variables than to hazardous variables.
- Hypothesis 5: The Driving Theory Test, as a measure of a driver's declarative knowledge, will be significantly related to hazard detection skill, which also appears to tap into declarative knowledge of driving.
- Hypothesis 6: The Driving Theory Test, as a measure of a driver's declarative knowledge, will not be significantly related to performance on the hazard handling test, a measure of a drivers' procedural skill.
- Hypothesis 7: The results obtained in version one of the hazard detection and hazard handling tests will be replicated using version two.

3.2 Method

3.2.1 Participants

A total of 36 participants completed this study. There were two experience groups; novice drivers and experienced drivers. The novice group (8 male, 10 female) consisted of 18 drivers with less than two years' experience (M=1.01yrs, SD=0.66), and an age range of 19.40 years to 23.35 years (M=20.68yrs; SD=0.98). The experienced group (9 male, 9 female) consisted of 18 drivers with between 5 and 15 years driving experience (M=6.85yrs, SD=2.80), and an age range of 21.50 years to 36.84 years (M=24.26yrs; SD=3.58). The groups differed significantly in terms of experience ($t(34)=-8.62$, $p<0.001$), and age ($t(3)=-4.09$, $p<0.001$). All participants completed both hazard perception tests with the order counterbalanced to negate ordering effects.

3.2.2 Refining Measures of Hazard Detection and Hazard Handling

The same hazard perception drive was used in both the hazard detection and hazard handling conditions. Once again, the drive consisted of five different speed zones i.e. 25kph, 40kph, 60kph, 70kph and 100kph; each containing various types of hazards (see Table 24) including bends of different curvature, traffic lights with amber onset at different times, pedestrians with continuous and interrupted visibility, car emerging events and following tasks. The counterbalancing order was as follows:

Drive 1: 40kph, 100kph, 70kph, 25kph, 60kph
Drive 2: 25kph, 60kph, 70kph, 100kph, 40kph
Drive 3: 70kph, 40kph, 25kph, 60kph, 100kph
Drive 4: 100kph, 25kph, 60kph, 40kph, 70kph

The time at which each hazard started moving differed from study one. In addition, each hazard was presented in each speed zone from 40kph to 100kph to prevent a confounding of speed and response time. The number of seconds participants were from each hazard at the point at which it started to move is presented in Table 24.

Table 24: Times at which hazardous events are triggered in version two of the Hazard Detection and Hazard Handling tests

Hazard	Levels	No.	25kph	40kph	60kph	70kph	100kph
Car Emerging (Trigger)		4		4s	4s	4s	4s
Merging Traffic (Trigger)		4		3s	3s	3s	3s
Pedestrians (Trigger)	Continuous Visibility	4		5s	5s	5s	5s
	Interrupted Visibility	4		5s	5s	5s	5s
Bend (Radius)	Large Curvature	8	50m	65m		320m	880m
	Medium Curvature	8	35m	50m		200m	660m
	Small Curvature	8	20m	30m		100m	340m
Traffic Light (Amber Onset)	Safe Stopping Zone	4		3.09s	3.88s	4.17s	5.47s
	Dilemma Zone	4		2.35s	3.01s	3.25s	3.97s
	Safe Crossing Zone	4		1.74s	2.16s	2.28s	2.49s

There were a total of fifty-two hazards included in the drive. Firstly, there were six bends in each of the speed zones outlined in Table 24, with three levels of bend curvature (small, medium, large) and two levels of visibility (continuous and limited). In this study, the bends with limited visibility were surrounded by trees rather than houses. There were twelve traffic light hazards, with three amber light zones occurring in all four speed zones. There were two pedestrian hazards in each speed zone (one continuous visibility and one interrupted visibility), leading to a total of eight pedestrian hazards. Finally, there was one car emerging, and one merging traffic hazard in each of the four speed zones outlined in Table 24.

3.2.2.1 Control Variables

In addition to the hazardous events described above, thirty-six control events were included. There were twenty straight stretches of road included in between bends. There was one control traffic light in each speed-zone which remained green throughout. There was also one pedestrian, one car-emerging, and one merging-traffic control event in each of the 40kph, 60kph, 70kph, and 100kph speed zones. These looked similar to the hazard events from a distance but did not move at any stage.

3.2.3 Driving Theory Test

In addition to the hazard perception tests, this study included a driver theory test. This was based on the Irish theory test, which all learner drivers are required to pass before receiving their provisional driving license. The test consisted of 40 randomised questions on topics including rules of the road, risk perception, hazard awareness, and good driving behaviour. It was based on the practice CD-ROM released by the RSA which contains every official question that may be asked in the theory test. Sample tests on the CD are presented in exactly the same format as the official test. Participants were given a total of 45 minutes to complete the test, and they needed a score of 35 or higher to pass. The software did not allow access to response times to individual questions, therefore the overall response time to each question was recorded and averaged to give an overall response time measure.

3.2.4 Design and Procedure

The procedure was almost the same as for the studies outlined in Chapter 2. On initial arrival to the driving simulator laboratory, participants completed an informed consent form, and a questionnaire which provided background information on age, gender, driving experience, and educational background; along with the SSQ, which provided a baseline measure of their wellbeing. Due to a stricter screening process, no participants had to drop out as a result of simulator sickness in this study. After the SSQ, participants completed a 10 minute practice drive, after which the hazard detection/hazard handling test was explained in detail to them. For the hazard detection test all aspects of the drive i.e. speed, lateral position, headway etc. were controlled externally and participants were asked to sound the horn every time they saw a potential driving hazard. This was defined as “any situation in which a collision or near collision with another road user or external object could occur unless you take some type of evasive action (e.g. braking, steering etc.)” (adapted from Wallis & Horswill, 2007, p. 1181). For the hazard handling condition, drivers were instructed to drive as they normally would, and the word hazard was not mentioned. When participants completed their first drive they were given a five minute break prior to completing the Driver Theory Test. Once they had completed this test they went back into the simulator to do their second hazard test. The order in which the drives were presented was counterbalanced to account for any ordering effects. Once again, each of the hazard perception tests took approximately 25 minutes to complete.

A mixed between-within subjects design was adopted for this study, with the performance of experienced and novice drivers being compared in terms of their reactions to the different types of hazard. There were two dependent variables in both the hazard detection and hazard handling tests:

- Drivers’ response rate i.e. the number of hazards participants responded to either through pressing the horn in the hazard detection condition, or making a change in their pedal/steering behaviour of 2SD in the hazard handling condition.
- Drivers’ response time i.e. how quickly after the hazard was triggered participants either made a horn response (hazard detection) or changed their driving behaviour (hazard handling)

The independent variables were participant’s level of driving experience (between-subjects), and hazard category (within-subjects).

3.3 Results

In this section the results of the second version of the hazard detection and hazard handling tests will be discussed. As the studies outlined in Chapter 2 provide evidence of the difficulty of separating out the effects of age and experience on hazard perception, all of the analyses included in this chapter will include age as a covariate.

3.3.1 Hazard Detection Test: Version 2

Mixed between-within groups analyses of covariance were conducted to compare the performance of novice and experienced drivers on the various hazard categories i.e. car emerging, merging traffic, pedestrians, traffic lights and bends, controlling for age. The results of these analyses are presented in the following sections.

3.3.1.1 Response Rate to Hazards

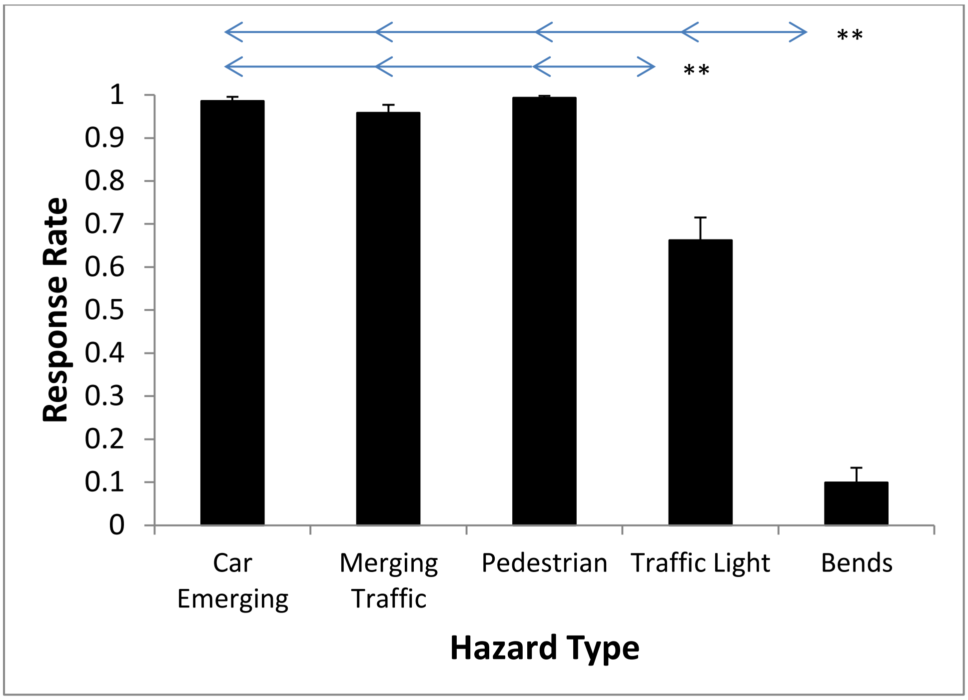
To begin, a two-way mixed between-within groups analysis of covariance was conducted to assess the impact of experience (between groups) and hazard category (within groups) on the response rate to hazards, controlling for any age effects. Overall, participants responded to 73.98% of the hazards presented. The results are presented in Table 25.

Table 25: Effects of experience group and hazard category on response rates in version 2 of the Hazard Detection test, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.28	0.60	0.01
Experience Group	1,33	<0.001	0.98	<0.01
Hazard Category	4,30	3.83	0.01	0.10
Hazard Category * Experience	4,30	0.62	0.65	0.02

Neither age ($F(1,33)=0.28$, $p=0.60$) nor experience group ($F(1,33)<0.001$, $p=0.98$) had any significant effect on response rates to hazardous events, with novice and experienced drivers responding to a similar number of events (M=0.74, SE=0.02).

There was a significant effect of hazard category on response rate ($F(4,30)=3.83$, $p<0.01$, $\eta_p^2=0.10$). This is presented in Figure 24 below.



**p<0.01

Figure 24: Response rates to individual hazard categories in version 2 of the Hazard Detection test (mean values, error bars represent standard error)

A post-hoc Bonferroni comparison of means showed that participants made significantly fewer responses to bends than to any other hazard (MD>0.56, p<0.001). Participants also responded to significantly fewer traffic light events than to any of the hazards involving other road users i.e. pedestrians, cars emerging, and merging traffic events (MD>0.29, p<0.001). This suggests that drivers are less likely to consider a traffic light as hazardous, compared to events involving other road users. There were no significant differences in response rates to car emerging, merging traffic, and pedestrian hazards, with participants responding to over 90% of each of these hazards. The very low detection rate of bends (10%) suggests that the majority of participants did not consider bends to be hazardous events, irrespective of severity of the curve.

As with the first version of the hazard detection test, there were no significant experience differences in response rates to hazardous events presented in an immersive environment. There was however, a difference in the detection rates of hazards involving other road users and hazards involving elements of the environment, with participants responding to significantly fewer bends and traffic light events than any other hazard.

3.3.1.2 Response Time to Hazards

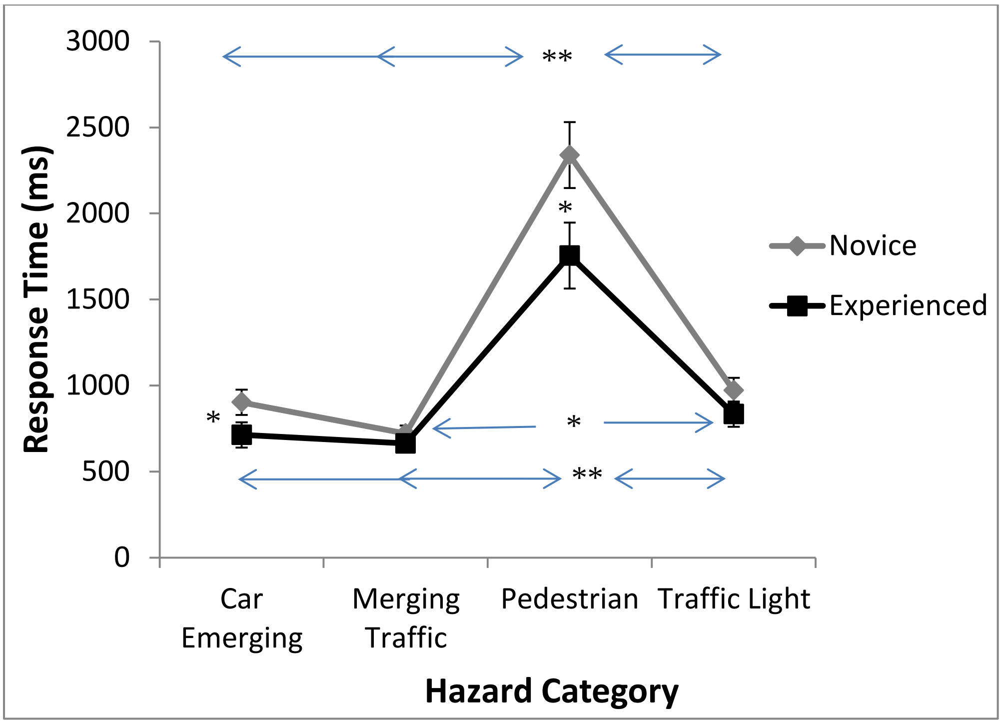
A two-way mixed between-within groups analysis of covariance was also conducted to assess the impact of hazard category and experience group on the response time to hazards. Bends were not included in the analysis as there were too few responses (10%) for meaningful comparisons. For all other hazards, missing values were replaced by the mean response time for that particular hazard, leading to the replacement of 10.02% of cases. The results are presented in Table 26.

Table 26: Effects of experience group and hazard category on response times in version 2 of the Hazard Detection test, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.05	0.82	0.002
Experience Group	1,33	3.54	0.07	0.10
Hazard Category	3,31	1.71	0.17	0.05
Hazard Category * Experience	3,31	3.11	0.03	0.09

Age did not have a significant effect on response time to hazards ($F(1,33)=0.05$, $p=0.82$). The effect of experience approached significance ($F(1,33)=3.54$, $p=0.07$), and a medium effect size of 0.10 suggests that this is a meaningful difference. Experienced drivers (M=991ms, SE=83) responded more quickly to hazards than novice drivers (M=1233ms, SE=83).

Although, there was no significant main effect of hazard category on response time to hazards ($F(3,31)=1.71$, $p=0.17$), there was a medium significant interaction between experience group and hazard type ($F(3,31)=3.11$, $p<0.01$, $\eta_p^2=0.09$) which is explored in Figure 25 below.



*p<0.05, **p<0.01

Figure 25: Interaction between response time and hazard category on response times in version 2 of the Hazard Detection test(mean values, error bars represent standard error)

Both car emerging ($t(34)=2.19$, $p<0.05$, $|d|=0.73$) and pedestrian hazards ($t(34)=2.52$, $p<0.05$, $|d|=0.84$) successfully discriminated between novice and experienced drivers, with novices having significantly slower response times to these hazards than experienced drivers. Experience group did not affect response time to merging traffic events ($t(34)=1.45$, $p=0.16$, $|d|=0.48$) or traffic light events ($t(34)=1.58$, $p=0.12$, $|d|=0.53$).

These results show that a tightly controlled hazard detection test can discriminate between novice and experienced drivers response times to certain hazards involving other road users, particularly cars emerging and pedestrians.

3.3.1.3 Examples of Hazard Responses: Pedestrians and Traffic Lights

As explained in Chapter 2, there were two types of hazard included in this study. One involved participant's interactions with other road users, in particular other car users and pedestrians. The other type of hazard event involved participant's interactions with fixed elements of the driving environment, in particular bends and traffic lights. In this section, a thorough analysis of pedestrian and traffic light events will be conducted to provide an example of participants' response patterns to different levels of these hazards.

3.3.1.4 Example of Hazards Involving Other Road Users: Pedestrians with Continuous and Interrupted Visibility

As with the first version of the hazard tests, there were two types of pedestrian hazard included in this study. Pedestrians with continuous visibility were fully visible at all times from the point at which they started to move, whereas pedestrians with interrupted visibility disappeared behind a parked jeep for a period of 1 second before emerging onto the road. Both sets of pedestrians were situated 12.2m from the centre line of the road, and began to move when the participant was 5 seconds away. Their speed of movement was linked to participant travelling speed and was designed to ensure that they would step out on the road before the participant passed them.

Response frequency was averaged across the speed zones for pedestrians with continuous and interrupted visibility. The results of an analysis of covariance comparing the response rates of the two experience groups (between-groups) to pedestrians with differing visibility levels (within-groups) are presented in Table 27.

Table 27: Effects of experience group and pedestrian visibility on response rates to pedestrian hazards in version 2 of the Hazard Detection test, with age as a covariate

Pedestrian Hazards	Df	F	P	η_p^2
Age	1,33	0.003	0.95	<0.001
Experience Group	1,33	1.46	0.24	0.04
Pedestrian Visibility	1,33	<0.01	0.98	<0.01
Visibility * Experience	1,33	<0.01	0.99	<0.01

Neither age ($F(1,33)=0.003$, $p=0.95$), nor experience ($F(1,33)=1.46$, $p=0.24$), had a significant effect on response rates to pedestrian hazards, with all of the experienced drivers (M=1.00, SE=0.01) and almost all of the novice drivers (M=0.99, SE=0.01) responding to all of the potential pedestrian hazards. This high response rate occurred irrespective of pedestrian visibility, with participants responding to 99.3% (SE=7.0) of both continuous and interrupted visibility pedestrians ($F(1,33)<0.01$, $p=0.98$).

Table 28 shows the results of the analysis of covariance on response time to pedestrian events, with age as a covariate. Response time was averaged across the speed zones for pedestrians with continuous and interrupted visibility, and any missing values were replaced with the mean response time to that particular hazard, leading to the replacement of 1.0% of cases.

Table 28: Effects of experience group and pedestrian visibility on response times to pedestrian hazards in version 2 of the Hazard Detection test, with age as a covariate

Pedestrian Hazards	Df	F	P	η_p^2
Age	1,33	0.01	0.92	<0.001
Experience Group	1,33	3.93	0.06	0.11
Pedestrian Visibility	1,33	2.76	0.11	0.08
Visibility * Experience	1,33	2.13	0.15	0.06

Participant age did not have a significant effect on response times ($F(1,33)=0.01$, $p=0.92$). However, the difference between novice and experienced drivers approached significance and had a medium effect size ($F(1,33)=3.93$, $p=0.06$, $\eta_p^2=0.11$), with experienced drivers (M=1755ms, SE=194) responding more quickly than novice drivers (M=2349, SE=194).

Unlike the results reported for hazard detection in Chapter 2, there were no significant effects of pedestrian visibility on response time ($F(1,33)=2.76$, $p=0.11$). This suggests that the significant effect of visibility in the previous study may have been a result of the longer movement time rather than the visibility of the pedestrian.

3.3.1.5 Example of Hazards Involving Elements of the Traffic Environment: Traffic Light Events

This section will provide a further exploration of how participants responded to a fixed element of the traffic environment, namely traffic light events. Responses to traffic light events were averaged across speed-zones and two-way between-within groups analyses of covariance on the response rate and response time to traffic light events were conducted. There were three levels of traffic light zone; safe stopping zone, dilemma zone, and safe crossing zone (see Section 2.2.2.2.4 in Chapter 2 for a full description).

The results of an analysis of covariance comparing the response rates of the two experience groups (between-groups) to traffic lights with differing amber onset times (within-groups) are presented in Table 29.

Table 29: Effects of experience group and amber-onset zone on response rates to traffic lights in version 2 of the Hazard Detection test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,33	0.003	0.96	<0.001
Experience Group	1,33	0.002	0.97	<0.001
Amber Onset Zone	2,32	1.45	0.24	0.04
AO Zone * Experience	2,32	0.43	0.65	0.01

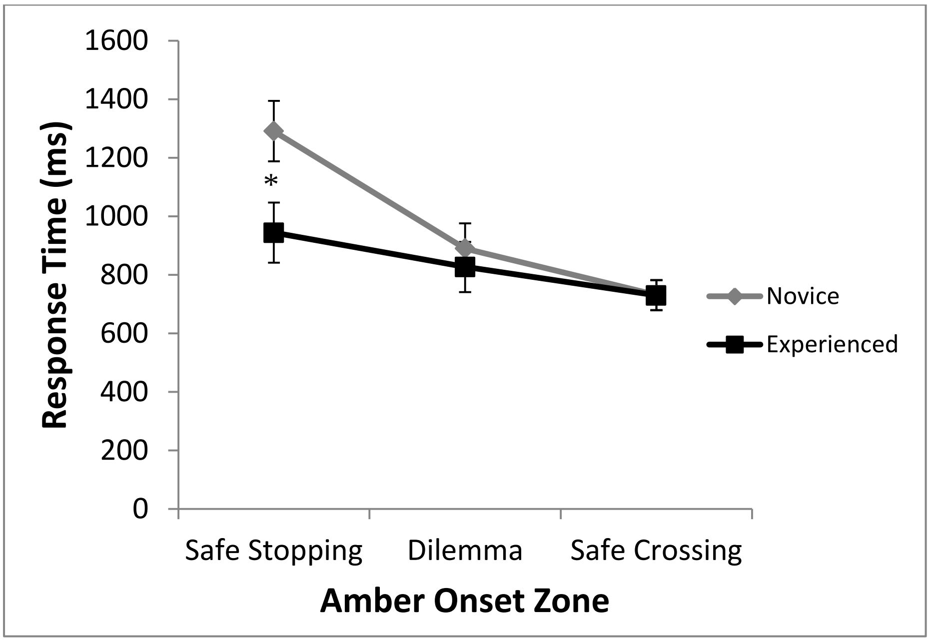
There was no significant effect of age (F(1,33)=0.003, p=0.96) or experience group (F(1,33)=0.002, p=0.97) on response rate to traffic lights with both experience groups responding to an average of 67% (SE=8.5) of amber onsets. There was also no significant difference in response rates across the three amber onset zones (F(2,32)=1.45, p=0.24).

Prior to analysing the response time data, missing values were replaced with the mean for each amber onset zone, leading to the replacement of some 33% of cases. The results of an analysis of covariance comparing the response rates of the two experience groups (between-groups) to traffic lights with differing amber onset times (within-groups) are presented in Table 30.

Table 30: Effects of experience group and amber-onset zone on response times to traffic lights in version 2 of the Hazard Detection test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,33	0.02	0.89	<0.001
Experience Group	1,33	1.44	0.24	0.04
Amber Onset Zone	2,32	1.21	0.31	0.04
AO Zone * Experience	2,32	6.74	0.002	0.17

Neither age (F(1,33)=0.02, p=0.89), nor experience group (F(1,33)=1.44, p=0.24), had a significant effect on response times to amber onset at traffic lights. There was, however, a large, significant interaction between amber onset zone and experience group ($F(2,32)=6.74$, $p<0.01$, $\eta_p^2=0.17$). This is displayed in Figure 26.



*p<0.05

Figure 26: Interaction between experience group and amber-onset zone on response time to traffic lights in version 2 of the Hazard Detection test(mean values, error bars represent standard error)

Independent samples t-tests show that there was no difference in the response times of novice and experienced drivers in the safe crossing ($t(34)=-0.11$, $p=0.91$, $|d|=0.04$) or dilemma zones ($t(34)=1.15$, $p=0.26$, $|d|=0.38$). However, experienced drivers made significantly faster hazard detections than novice drivers when amber onset occurred in the safe stopping zone ($t(34)=2.49$, $p<0.05$, $|d|=0.83$). This suggests that experienced drivers saw a need to change behaviour immediately at amber onset, regardless of how far away the traffic light was. Novice drivers may have believed that they had more time to react when amber onset occurred in the safe stopping zone, and thus responded more slowly to these types of traffic lights.

The only difference in results for traffic light events between the first and second version of the hazard detection test was the existence of an interaction between experience and amber onset zone in the second version. It would appear that there was no difference between novice and experienced drivers response rates to amber onsets at traffic lights. However, experienced drivers were quicker to respond to amber onsets in the safe stopping zone than novice drivers, suggesting they saw a need to change behaviour immediately at amber onset even if the traffic light was far away.

3.3.1.6 Control Variables

In the previous version of the hazard tests, particularly the hazard handling test, there was some concern that very high response rates might be an indication of poor response criterion. Wetton et al. (2011) in their guidelines for the development of hazard perception tests advocate that tests should be able to identify and classify inappropriate responses, thereby facilitating the detection of people over-responding or trying to cheat the test. In order to evaluate whether or not participants were over-responding, a number of control variables were included in this version of the hazard detection test (see Section 3.2.2.1). A two-way mixed between-within groups analysis of covariance was conducted to compare the number of responses to hazard events and control events (within groups) by experienced and novice drivers (between groups) in the hazard detection study. The results of this analysis are presented in Table 31.

Table 31: Comparing response rates to hazard and control variables in version 2 of the Hazard Detection test, controlling for age

	Df	F	p	η_p^2
Age	1,33	0.15	0.70	0.004
Experience Group	1,33	0.74	0.39	0.02
Hazardousness (hazard/control)	1,33	4.82	0.04	0.13
Hazardousness * Experience	1,33	1.39	0.25	0.04

Experience group did not have a significant effect on the number of responses made across variable types i.e. hazard or control ($F(1,33)=0.74$, $p=0.39$), with novice drivers responding to an average of 39.6% of events (SE=2.2) and experienced drivers responding to an average of 42.6% (SE=2.2).

There was a medium significant effect of variable hazardousness (i.e. hazard or control) on the number of responses made ($F(1,33)=4.82$, $p<0.05$, $\eta_p^2=0.13$). Participants made significantly more responses to hazardous events (M=0.74, SE=0.02), than to control events (M=0.08, SE=0.02).

A three-way mixed between-within groups analysis of covariance was also conducted to compare the response times to hazard and control events in the hazard detection test (see Table 32).

Table 32: Comparing response times to hazard and control variables in version 2 of the Hazard Detection test, with age as a covariate

	Df	F	p	η_p^2
Age	1,17	0.23	0.64	0.01
Experience Group	1,17	0.62	0.44	0.04
Hazardousness (hazard/control)	1,17	0.56	0.47	0.03
Hazardousness * Experience	1,17	0.45	0.51	0.03

There was no significant difference between novice (M=1485ms, SE=291) and experienced drivers (M=1130ms, SE=254) response times across the two test and variable (hazard/control) types ($F(1,17)=0.62$, $p=0.44$). In the overall analysis, the main effect of variable hazardousness was not significant ($F(1,17)=0.56$, $p=0.51$). However, a post hoc Bonferroni comparison of means suggests that the difference was reliable (MD=0.64, $p=0.03$), with participants responding more quickly to hazardous (988ms, SE=51) than control events (M=1627ms, SE=282).

Analysis of responses to control variables shows that participants responded to dramatically fewer control features of the environment than to hazardous features. This provides evidence that the test is evaluating true hazard responses.

3.3.1.7 Summary of Results for Hazard Detection Test

The second version of the hazard detection test appears to successfully discriminate between novice and experienced drivers, at least in terms of response time to some hazards. Experienced drivers had reacted more quickly to both pedestrian and car emerging hazards in this test than novice drivers.

As with the first version of the test, it would appear that participants make fewer responses to elements of the driving environment such as bends and traffic lights than to hazards involving other road vehicles and pedestrians. Participants responded most quickly to bends and most slowly to pedestrian events. A more detailed analysis of pedestrian events showed that the slow response times were due to novice drivers taking a long time to respond to pedestrian events. However, unlike the first study there was no difference in response times to pedestrians with interrupted and continuous visibility, suggesting that it was the longer movement time of the interrupted visibility pedestrians which had led to the a difference in response times in the first study.

A deeper analysis of traffic light events showed that there was no difference between novice and experienced drivers response rates to amber onset at traffic lights. However, it appeared that there was a difference in the response times of novice and experienced drivers in relation to traffic lights which had amber onset in the safe stopping zone. Novice drivers did not respond as quickly as experienced drivers to amber onsets occurring in this zone, although there were no differences between the groups in responding to amber lights in the other zones.

3.3.2 Hazard Handling Test: Version 2

As with version one of the hazard handling test, participants in version two had full control of the simulator vehicle, and negotiated the same route as in the hazard detection study (the order of speed-zones differed). A response was taken to be a change in speed or directional control greater than 2SD over the duration of the hazard.

3.3.2.1 Response Rate to Hazards

Response rate was measured by checking whether or not a change of 2SD in pedal/steering behaviour occurred from the point at which the hazard was triggered to the point at which the participant passed the hazard. Overall, participants changed their behaviour by 2SD or more in relation to 93% of hazards presented.

A mixed between-within groups analysis of covariance was conducted to compare the performance of novice and experienced drivers (between groups) across the various hazards i.e. car emerging, merging traffic, pedestrians, traffic lights and bends (within groups). The results of these analyses are presented in Table 33.

Table 33: Effects of experience group and hazard category on response rates in version 2 of the Hazard Handling test, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.04	0.84	0.001
Experience Group	1,33	0.01	0.93	<0.001
Hazard Category	4,30	0.68	0.61	0.02
Hazard Category * Experience	4,30	0.51	0.73	0.02

There was no significant effect of age ($F(1,33)=0.04$, $p=0.84$) or experience group on the response rate to hazards in the hazard handling condition ($F(1,33)=0.01$, $p=0.93$), with both novice and experienced drivers responding to a similar number of hazards ($M=0.93$, $SE=0.01$). In this version of the test, hazard category did not affect response rates ($F(4,30)=0.68$, $p=0.61$).

3.3.2.2 Response Time to Hazards

Response time was measured as the time from when a hazard was initially triggered to the point at which a steering/accelerator/brake change of 2SD occurred. Missing values were replaced with the mean response time to a given hazard, leading to the replacement of 7.25% of cases.

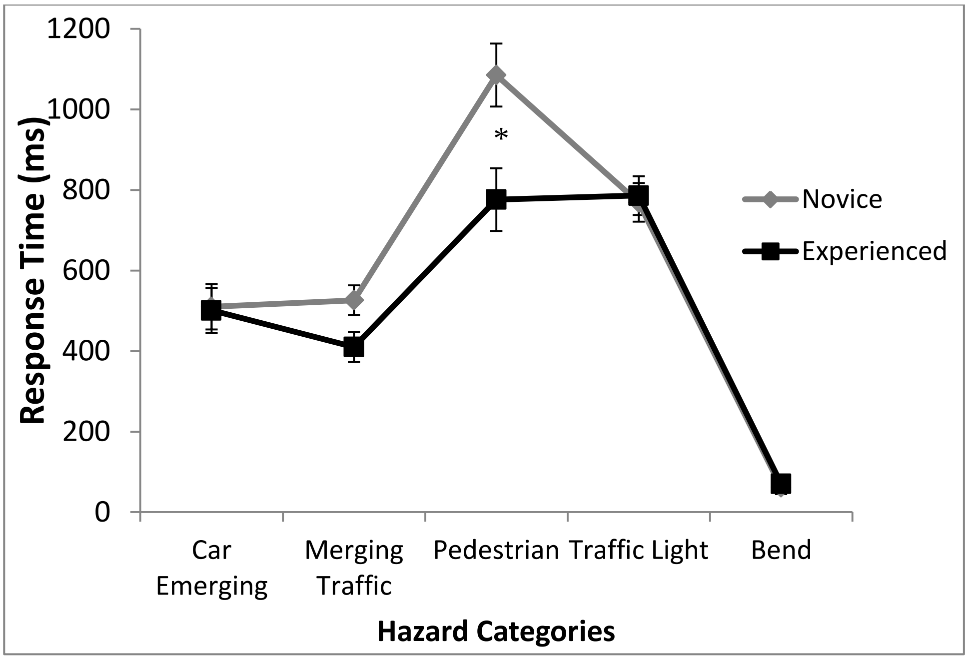
A two-way mixed between-within groups analysis of covariance was conducted to assess the impact of experience group (between groups) and hazard category (within group) on the response time to hazards. The results are presented in Table 34.

Table 34: Effects of experience group and hazard category on response times in version 2 of the Hazard Handling test, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.002	0.97	<0.001
Experience Group	1,33	6.24	0.02	0.16
Hazard Category	4,31	1.81	0.13	0.05
Hazard Category * Experience	4,31	2.90	0.02	0.08

There was a large significant effect of experience group on response time ($F(1,33)=6.24$, $p<0.05$, $\eta_p^2=0.16$), with experienced drivers ($M=509$ms, $SE=21$) making significantly faster responses than novice drivers ($M=590$ms, $SE=21$).

Although there was no significant main effect of hazard category on response time ($F(4,31)=1.81$, $p=0.13$), there was a medium significant interaction between hazard category and experience group ($F(4,31)=2.90$, $p<0.05$, $\eta_p^2=0.08$), displayed in Figure 27.



*p<0.05

Figure 27: Interaction between experience group and hazard category on response time in version 2 of the Hazard Handling test (mean values, error bars represent standard deviation)

As Figure 27 shows, there were no significant experience-related differences in response time to car emerging, traffic light, or bend hazards. Independent and paired-samples t-tests were conducted to further explore the relationships. There was a significant experience effect on response time to pedestrian events ($t(34)=3.03$, $p<0.01$, $|d|=1.01$) with novice drivers ($M=1.08$, $SE=0.35$) taking significantly longer to respond than experienced drivers ($M=0.77$, $SE=0.26$). The difference between novice and experienced drivers response times to merging traffic hazards approached significance ($t(34)=1.82$, $p=0.08$, $|d|=0.61$) with novice drivers ($M=0.51$, $SE=0.17$) once again taking longer to respond than experienced drivers ($M=0.42$, $SE=0.11$). A medium Cohen's *d* effect size of 0.61 suggests that this is a meaningful difference.

The pattern of response times to hazards was similar in this study to version one of the test. Participants responded most quickly to bends and most slowly to pedestrian events. It appeared that in this condition, pedestrian and merging traffic events showed the best discrimination between novice and experienced drivers.

3.3.2.3 Example of Hazards Involving Other Road Users: Pedestrians with continuous and interrupted visibility

As in the hazard detection test, there were two types of pedestrian hazard included in this study. Pedestrians with continuous visibility were fully visible at all times from when they started to move, whereas pedestrians with interrupted visibility disappeared behind a parked jeep for approximately one second before emerging onto the road (the length of time was dependent on how fast the participant was travelling).

Response frequency was averaged across the speed zones for pedestrians with continuous and interrupted visibility. Participants responded to a total of 99% of pedestrian events. The results of a two-way mixed between-within subjects analysis of variance evaluating the effects of experience groups (between-groups variable) and pedestrian visibility (within-groups variable) on response rates to pedestrians are presented in Table 35.

Table 35: Effects of experience group and pedestrian visibility on response rates to pedestrian hazards in version 2 of the Hazard Handling test, with age as a covariate

Pedestrian	Df	F	p	η_p^2
Age	1,33	0.004	0.95	<0.001
Experience Group	1,33	1.15	0.29	0.03
Pedestrian Visibility	1,33	0.08	0.78	0.002
Visibility * Experience	1,33	0.50	0.49	0.02

There were no significant effects of either age ($F(1,33)<0.01$, $p=0.95$) or experience group ($F(1,33)=1.15$, $p=0.29$) on response rate to pedestrian hazards; with participants responding to the majority of pedestrians with continuous ($M=0.99$, $SE=0.01$) and interrupted visibility ($M=0.99$, $SE=0.01$).

A two-way mixed between-within groups analysis of covariance was also conducted on response times to pedestrian hazards (see Table 36). Missing values were replaced by the mean response time for each pedestrian variable, leading to the replacement of 1.0% of cases.

Table 36: Effects of experience group and pedestrian visibility on response times to pedestrian hazards in version 2 of the Hazard Handling test, with age as a covariate

Pedestrians	Df	F	p	η_p^2
Age	1,33	<0.001	0.99	<0.001
Experience Group	1,33	6.49	0.02	0.16
Pedestrian Visibility	1,33	0.86	0.36	0.03
Visibility * Experience	1,33	0.03	0.87	0.001

Experienced drivers (M=776ms, SE=78) responded significantly more quickly to pedestrian hazards than novice drivers (M=1085ms, SE=78), and this was a large effect ($F(1,33)=6.49$, $p=0.02$, $\eta_p^2=0.16$).

However, as when age was included in Chapter 2, there was no significant effect of pedestrian visibility on response rate ($F(1,33)=0.86$, $p=0.36$) with participants taking approximately 816ms to respond to pedestrians with continuous visibility (SE=46) and 1045ms to respond to pedestrians with interrupted visibility (SE=81). This supports the conclusion emerging from the hazard detection test that it was not the visibility of the pedestrian which led to longer response times in version one of the hazard tests, but the difference of the movement time which provided them with more time to react to pedestrians with interrupted visibility.

3.3.2.4 Exploring Further: Traffic Light Events

Once again, response rate and response frequency were averaged across speed-zones for traffic light events. Two-way between-within subjects' analysis of covariance were conducted examining the impact of amber onset zone (within-subjects) and experience group (between subjects) on the response rate and response time to traffic light events. There were three levels of amber onset zone; safe stopping zone, dilemma zone, and safe crossing zone (see Section 2.2.2.2.4 in Chapter 2 for a full description).

The results of the analysis of covariance examining the effect of experience group and amber onset zone on response rate are presented in Table 37. Overall participants responded to 69% of amber onsets.

Table 37: Effects of experience group and amber-onset zone on response rates to traffic lights in version 2 of the Hazard Handling test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,33	0.01	0.91	<0.001
Experience Group	1,33	0.18	0.68	0.01
Amber Onset Zone	2,32	1.20	0.31	0.04
AO Zone * Experience Interaction	2,32	0.05	0.95	0.002

There was no significant effect of age ($F(1,33)=0.01$, $p=0.91$), experience group ($F(1,33)=0.18$, $p=0.68$), or amber onset zone ($F(2,32)=1.20$, $p=0.31$) on response rate to traffic lights in the hazard handling condition. Participants responded to an average of 82.6% (SE=3.7) of amber onsets in the safe stopping zone, 73.6% (SE=4.2) amber onsets in the dilemma zone, and 50.7% (SE=4.3) amber onsets in the safe crossing zone.

A two-way between-within groups' analysis of covariance was also conducted to evaluate the effect of experience group and traffic light zone on response time to traffic lights (see Table 38). As in the previous analyses, missing values were replaced with the mean for each particular amber onset zone, leading to the replacement of some 31% of cases.

Table 38: Effects of experience group and amber-onset zone on response times to traffic lights in version 2 of the Hazard Handling test, with age as a covariate

Traffic Lights	Df	F	p	η_p^2
Age	1,33	0.06	0.81	0.002
Experience Group	1,33	0.73	0.40	0.02
Traffic Light Zone	2,32	.0.39	0.68	0.01
TL Zone * Experience Interaction	2,32	1.19	0.31	0.04

Age did not have a significant effect on response times to traffic lights ($F(1,33)=0.06$, $p=0.81$), nor was there any significant effect of experience group

(F(1,33)=0.73, p=0.40). Novice (M=0.84, SE=0.05) and experienced drivers (M=0.82, SE=0.05) took a similar amount of time to respond to traffic lights.

Amber-onset zone also did not significantly impact response times (F(2,33)=0.39, p=0.68), with participants taking approximately 746ms (SE=55) to change their behaviour in the safe stopping zone, 753ms (SE=44) in the dilemma zone, and approximately 976ms (SE=62) when they were in the safe crossing zone. This result is similar to that obtained in version one when age was included in the model, and suggests that distance from traffic lights at amber onset does not greatly influence the time taken for drivers to change their behaviour.

3.3.2.5 Control Variables

The high number of responses to hazards, particularly in the hazard handling condition, led to some concerns that the criterion for response was not strict enough to detect real hazard responses. In order to determine whether or not this was the case, a number of control variables were included to allow a comparison between driving responses when there were no hazards present and driving responses when a hazard was present.

A two-way mixed between-within groups analysis of covariance was conducted to compare the number of responses to hazard events and control events (within groups) by experienced and novice drivers (between groups) in the hazard handling study, with age as a covariate. The results of this analysis are presented in Table 39.

Table 39: Comparing response rates to hazard and control variables in version 2 of the Hazard Handling test, with age as a covariate

	Df	F	P	η_p^2
Age	1,33	0.30	0.59	0.01
Experience Group	1,33	0.08	0.79	0.002
Hazardousness (hazard/control)	1,33	10.73	0.002	0.25
Hazardousness * Experience	1,33	0.08	0.79	0.002

Age did not have a significant effect on the response rates across the hazard and control variables (F(1,33)=0.30, p=0.59). There was also no significant effect of experience group on the number of responses made across variable types i.e. hazard or control ($F(1,33)=0.08$, $p=0.79$), with both novice and experienced drivers making an equal number of responses ($M=0.69$, $p=0.02$)

There was a large significant effect of variable hazardousness (i.e. hazard or control) on the number of responses made ($F(1,33)=10.73$, $p<0.01$, $\eta_p^2=0.25$). Participants made significantly more responses to hazardous events ($M=0.74$, $SE=0.01$), than to control events ($M=0.44$, $SE=0.02$).

A three-way mixed between-within groups' analysis of covariance was also conducted to compare the response times to hazard and control events in the hazard handling test (see Table 40).

Table 40: Comparing response times to hazard and control variables in version 2 of the Hazard Handling test, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.97	0.33	0.03
Experience Group	1,33	0.15	0.70	0.004
Hazardousness (hazard/control)	1,33	3.08	0.09	0.09
Hazardousness * Experience	1,33	0.15	0.71	0.004

Age had no significant effect on response times to hazard and control variables ($F(1,33)=0.97$, $p=0.33$). There was also no significant difference between novice ($M=852$ms, $SE=69$) and experienced drivers ($M=810$ms, $SE=69$) response times across the variable types i.e. hazard or control ($F(1,33)=0.15$, $p=0.70$). Although not significant at the $p<0.05$ level, the medium sized effect of variable hazardousness ($F(1,33)=3.08$, $p=0.09$, $\eta_p^2=0.09$) suggests a meaningful difference, with participants responding more quickly to hazardous events ($M=550$ms, $SE=13$) than control events ($M=1113$ms, $SE=86$).

The comparison of control and hazard variables provides reassurance about the response criteria used to establish a hazard response in the hazard handling test. The significantly lower response rate to control variables when compared to hazardous variables shows that participants were not changing their behaviour by 2SD or more in relation to every feature of the environment. The longer response time and larger error margin for control variables suggests that any changes in behaviour over 2SD surrounding the control variables were random rather than being related to a particular event.

3.3.2.6 Summary of Hazard Handling Results

The second version of the hazard handling test once again successfully discriminates between novice and experienced drivers overall response time to hazards. Experienced drivers had significantly faster response times in this test than novice drivers, particularly in relation to pedestrian and merging traffic hazards. There was no difference between the experience groups in the number of hazardous events they made responses to, nor was there a significant difference in the number of responses made to the different hazard categories.

A detailed analysis of pedestrian events showed that novice drivers took noticeably longer to respond to these types of hazards than experienced drivers. The level of visibility of pedestrians did not seem to impact on response times, suggesting that the visibility effect obtained in version one of the hazard handling test may have been confounded with movement time. A further analysis of traffic light events found no difference between the experience groups in their response rates or times to amber onsets. This is similar to the results obtained in version one when age was included in the model.

Comparing version two of the hazard handling and hazard detection tests shows that experienced drivers responded more quickly to hazards than novice drivers in both tests, with the difference being emphasised for car emerging and pedestrian events when participants were asked to make lever press responses to hazards, and for merging traffic and pedestrian events when in control of the vehicle themselves. This provides some indication that hazards involving other road users are more discriminatory than hazards involving elements of the environment.

3.3.3 Comparing Hazard Detection and Hazard Handling Tests

In order to evaluate the difference between the traditional hazard perception test and a more ecologically valid hazard handling test, a mixed between-within groups analysis of covariance was conducted, comparing the overall response frequency of novice and experienced drivers (between groups) across the two test types i.e. hazard detection and hazard handling (within groups), with age as a covariate. The results of this analysis are presented in Table 41.

Table 41: Comparing response rates in the second versions of the Hazard Detection and Hazard Handling tests, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.30	0.59	0.009
Experience Group	1,33	0.01	0.76	0.003
Hazard Test (Detection vs. Handling)	1,33	3.77	0.06	0.10
Hazard Test * Experience	1,33	0.11	0.74	0.003

Age did not have a significant effect on response rates across the two tests ($F(1,33)=0.30$, $p=0.59$). There was also no significant effect of experience group on the number of hazard responses made ($F(1,33)=0.01$, $p=0.76$), with novice and experienced drivers responding to a similar proportion of hazards (M=0.84, SE=0.02). The effect of hazard test approached significance ($F(1,33)=3.77$, $p=0.06$), with a medium partial eta squared effect size of 0.10 suggesting an examination of mean responses. Participants responded to a greater proportion of hazards in the hazard handling (M=0.94, SE=0.01) than in the hazard detection test (M=0.74, SE=0.02).

A mixed between-within groups analysis of covariance was also conducted to compare the overall response time to hazardous events of novice and experienced drivers (between groups) in the hazard perception and hazard handling tests (within groups; see Table 42).

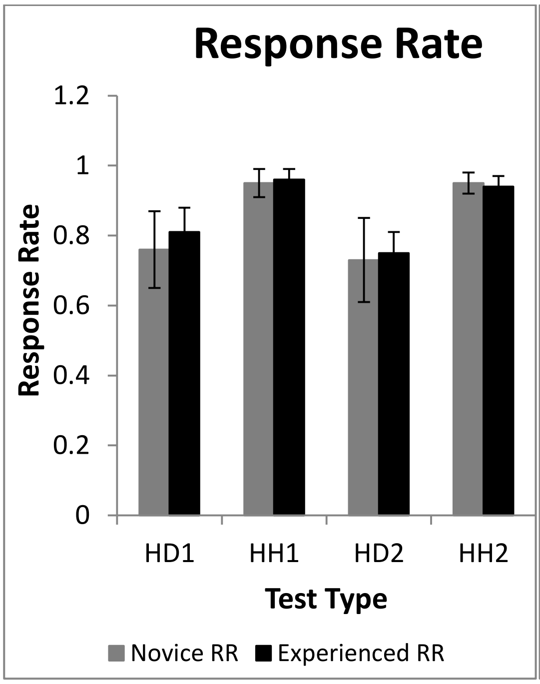
Table 42: Comparing response times in the second versions of the Hazard Detection and Hazard Handling tests, with age as a covariate

	Df	F	p	η_p^2
Age	1,33	0.05	0.82	0.002
Experience Group	1,33	6.75	0.01	0.17
Hazard Test (Detection vs. Handling)	1,33	1.73	0.19	0.05
Hazard Test * Experience	1,33	1.31	0.26	0.04

Age did not have a significant effect on response times to hazards across the two tests ($F(1,33)=0.05$, $p=0.82$). There was a large significant effect of experience group, above and beyond that of age ($F(1,33)=6.75$, $p<0.01$, $\eta_p^2=0.17$), with experienced drivers (M=750ms, SE=4.0) responding more quickly to hazards across the two tests than novices (M=910ms, SE=4.0). However, there was no significant effect of test type ($F(1,33)=1.73$, $p=0.19$), with participants taking an average of 1112ms to respond in the hazard detection condition (SE=53) and 550ms to respond in the hazard handling condition (SE=13).

3.3.4 Comparing Version 1 and Version 2

Figure 28 provides a summary of the results of version one and two of the hazard detection and handling tests.



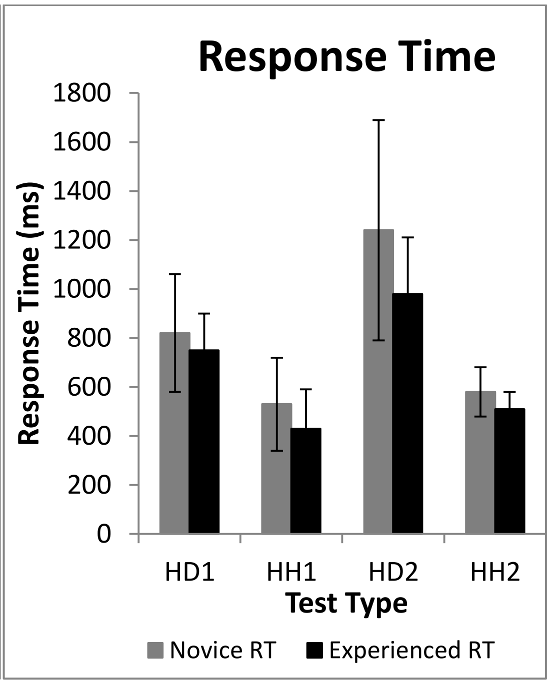


Figure 28: Comparing average response rates and response times to hazards in Version 1 & Version 2 (mean values, error bars represent standard error)

It is apparent that there is a great deal of consistency across performance in version one and version two. Response times were longer in the hazard detection test than in the hazard handling test in both cohorts, although this difference failed to reach significance when age was included as a covariate, suggesting that participant age may influence the relationship. In addition, there were a higher number of responses in the hazard handling test than in the hazard perception test across both cohorts. Experienced drivers showed consistently faster response times to hazards across all versions in both cohorts, although the experience differences did not always reach significance.

Table 43 provides a summary of the significant response time differences to individual hazard categories across the two versions of the hazard detection and hazard handling tests. There were no significant differences between the experience groups in response rate to any of the hazards and therefore only response times are included in the table.

Table 43: Summary of experience related differences in responses to individual hazard categories across all versions of the hazard detection and hazard handling tests, when age is included as a covariate

Hazard	Characteristics	Hazard Detection		Hazard Handling	
		Version 1: Response Time	**Version 2: Response Time**	**Version 1: Response Time**	**Version 2: Response Time**
Car Emerging			✓, $p<0.05$, d=0.73		
Merging Traffic					✓, $p=0.08$, d=0.61
Pedestrian			✓, $p<0.05$, d=0.84	✓, $p=0.03$, $\eta_p^2=0.13$	✓, $p=0.02$, $\eta_p^2=0.16$
	Continuous				
	Interrupted	✓, $p=0.10$, $\eta_p^2=0.08$			
Traffic Light		✓, $p=0.08$, $\eta_p^2=0.09$			
	Safe Stopping Zone		✓, $p<0.05$, d=0.83		
	Dilemma				
	Safe Crossing Zone				
Bends					

Effect sizes: η_p^2: 0.01=small, 0.06=medium, 0.14=large

Cohen's $|d|$: 0.20=small, 0.50=medium, 0.80=large

As Table 43 shows, the characteristics of particular hazard events led to them being more or less discriminative in terms of tapping into experience effects. Pedestrian events appeared to be the strongest discriminator, as there was a significant difference between novice and experienced drivers response times to pedestrian hazards in both versions of the hazard handling test, and in version two of the hazard detection test. Interactions with other vehicles also proved to have some discriminatory power, with novice drivers responding more slowly to car emerging events in the second version of the hazard detection test and to merging traffic events in the second version of the hazard handling test. Overall, these results provide evidence for looking at the characteristics of hazard situations when trying to determine what makes them safe/less safe for drivers.

3.4 Driving Theory Test

All participants completed a version of the Irish Driver Theory Test (DTT) along with the hazard drives. The purpose of this test was to assess participants' declarative knowledge of the rules of driving, along with establishing what relationships, if any existed between knowledge of driving theory and hazard detection and hazard handling skill.

Firstly, in order to establish whether or not there were any experience related differences in the knowledge of driving theory, an independent samples t-test was conducted comparing novice and experienced drivers' DTT scores and response times. Results indicate that experience had a significant effect on the number of correct responses made ($t(32)=-3.54$; $p<0.001$, $d=1.20$) with novice drivers (M=80.38%, SE=2.23) making fewer correct responses than experienced drivers (M=88.72%; SE=1.06). There was no significant difference between the groups in terms of average time taken to respond to questions ($t(33)=0.72$, $p=0.48$, $d=0.24$), with novice drivers taking an average of 18.77 minutes (SE=1.39) to complete the test, and experienced drivers taking an average of 17.50 minutes (SE=1.11).

3.4.1 Correlations

In order to investigate the relationships between driver theory test performance, and performance on the hazard detection and hazard handling tests, Pearson's correlation coefficients were calculated. Table 44 below provides a breakdown of the relationships emerging.

Table 44: Correlations between Driving Theory Test results and response rates and times in version 2 of the Hazard Detection and Hazard Handling tests

	N	M	SD	DDT	DDTrt	HDrr	HD-FArr	HDrt	HD-FArt	HHrr	HH-FArr	HHrt	HH-FArt
							Novice Drivers						
DTT Score	17	80.37	8.92	1									
DTT Mean Response Time	16	18.76	5.73	-0.20	1								
HD Response Rate Hazards	18	0.73	0.12	**0.62****	0.17	1							
HD Response Rate False Alarms	18	0.07	0.09	0.44	-0.04	0.39	1						
HD Response Time Hazards	18	1.24	0.38	-0.26	0.30	**-0.50***	-0.46	1					
HD Response Time False Alarms	9	1.71	1.22	0.09	0.34	0.30	-0.24	0.64	1				
HH Response Rate Hazards	18	0.95	0.03	0.04	-0.20	0.29	0.18	-0.43	-0.04	1			
HH Response Rate False Alarms	18	0.43	0.12	-0.30	0.41	-0.09	-0.28	0.35	0.13	-0.18	1		
HH Response Time Hazards	18	0.59	0.09	0.28	-0.37	-0.08	0.44	-0.34	0.47	0.09	-0.11	1	
HH Response Time False Alarms	18	1.17	0.57	0.13	-0.03	0.09	-0.02	-0.19	-0.41	-0.19	**-0.48***	0.08	1
							Experienced Drivers						
DTT Score	18	88.72	4.50	1									
DTT Mean Response Time	18	17.50	4.72	-0.05	1								
HD Response Rate Hazards	18	0.75	0.06	0.12	0.25	1							
HD Response Rate False Alarms	18	0.10	0.13	-0.08	0.27	0.15	1						
HD Response Time Hazards	18	0.98	0.22	-0.13	-0.14	0.10	-0.38	1					
HD Response Time False Alarms	11	1.51	1.23	-0.34	-0.34	-0.35	-0.14	0.27	1				
HH Response Rate Hazards	18	0.94	0.03	0.08	0.13	**0.53***	0.37	-0.24	0.01	1			
HH Response Rate False Alarms	18	0.44	0.11	0.13	-0.35	-0.02	-0.30	0.13	0.03	0.28	1		
HH Response Time Hazards	18	0.51	0.07	0.07	0.09	0.14	-0.07	-0.07	-0.06	-0.20	-0.16	1	
HH Response Time False Alarms	18	1.05	0.46	0.37	0.26	-0.15	-0.09	-0.30	0.17	-0.04	-0.19	0.09	1

**p<0.01, *p<0.05

The following abbreviations occur in Table 44:

- DTT – Driving Theory Test score i.e. percentage of questions answered correctly
- DTTrt – Driving Theory Test response time i.e. mean time taken to complete test
- HDrr – Hazard Detection Test response rate i.e. mean response rate to hazardous events
- HD-FArr – Hazard Detection Test, False Alarm response rate i.e. mean response rate to control events
- HDrt – Hazard Detection Test response time i.e. mean time taken to respond to hazards
- HD-Fart – Hazard Detection Test, False Alarm response time i.e. mean time taken to respond to control events
- HHrr – Hazard Handling Test response rate i.e. mean response rate to hazardous events
- HH-Farr – Hazard Handling Test, False Alarm response rate i.e. mean response rate to control events
- HHrt – Hazard Handling Test response time i.e. mean time taken to respond to hazards
- HH-Fart – Hazard Handling Test , False Alarm response time i.e. mean time taken to response to control events

It is interesting to note that there are more significant correlations among scores for the novice drivers than the experienced drivers. Cohen (1988) suggests that Pearson's *r* values of 0.10 to 0.29 represent a small relationship, values of 0.30 to 0.49 indicate a medium relationship, and values of 0.50 to 1.0 represent a large relationship between variables. There was a large significant correlation between novice drivers response rate to hazardous events in the hazard detection test, and driving theory test score (r=0.62, p<0.01). This suggests that the hazard detection test is tapping into a declarative awareness of driving rules, at least for novice drivers. There was also a large significant negative correlation between response time and response rate in the hazard detection test (r=-0.50, p<0.05), indicating that as the number of hazards participants responded to increased, the speed at which they responded decreased. Finally, there was a medium significant negative relationship between response rate and response time to false alarms in the hazard handling condition (r=-0.48, $p<0.05$). For experienced drivers, the only correlation which reached significance was between response rates in the hazard handling and hazard detection conditions (r=0.53, $p<0.05$).

The lack of any relationship between response times in the hazard detection and hazard handling tests is interesting, as it suggests that what is being measured in these tests is not the same. This appears to be particularly true for novice drivers, as for these drivers there is also no relationship between response rates in the hazard detection and hazard handling tests. Overall, these results suggest that the motor skills involved in actually selecting and implementing a response while driving in the hazard handling test are not significantly related to the skills involved in identifying hazardous events in a more passive hazard detection test.

3.5 Discussion

The results from this chapter show that both the hazard detection and hazard handling tests can discriminate between novice and experienced drivers' response times to hazardous events, particularly in terms of hazards involving other road users i.e. pedestrians and other vehicles. The fact that participants responded much more frequently in the hazard windows than in control windows provides support for our definition of hazardous events. In addition, this more tightly controlled hazard handling experiment succeeded in replicating the results obtained in version one of the hazard handling test, with an experience related difference actually emerging in version two of the hazard detection test. These results are the first to be collected in an interactive immersive assessment of hazard detection and hazard handling, providing a more ecologically valid measure of drivers' ability to detect and to respond to hazardous events than previous studies involving button press responses to hazards presented on a computer screen.

It is interesting that there were no significant experience differences in the number of responses made to hazards across the two test types, with both novice and experienced drivers having particularly high response rates to hazards involving other road users (i.e. other traffic, pedestrians) in both the hazard detection and hazard handling tests. Huestegge et al. (2010) found that overall response times to hazards presented in a static scene were faster for experienced drivers than novice drivers. However, there were no differences between the groups in terms of time until initial fixation on the hazard, suggesting that experienced drivers were better at processing hazard information than novice drivers. The results of the current study provide support for these findings. Although novice and experienced drivers responded to a similar number of hazardous events, experienced drivers were consistently faster at responding to the events, particularly in the hazard handling tests. This suggests that the experience-related differences in hazard perception emerge in the processing of hazard responses, rather than in the detection of hazardous events.

3.5.1 Driving Theory, Hazard Detection & Hazard Handling: Applying the Cognitive Model of Driving

The process of skill acquisition can be broken into declarative and procedural stages (Anderson, 1982). The current study provides support for the idea that traditional hazard perception tests (requiring a discrete response to hazards) may be tapping more into declarative knowledge of driving, rather than procedural knowledge. The correlation between driving theory test score and accurate response rate in the hazard detection condition suggests that both tests are measuring similar skills, particularly where novice drivers are concerned. It can be assumed that the driving theory test measures declarative knowledge of driving, as it is examining explicit knowledge of the rules of the road. Therefore, it would appear that the hazard detection test also places a greater emphasis on declarative knowledge of what constitutes a hazard. There was no correlation between the theory test and the hazard handling condition, where procedural knowledge of the processes involved in driving is required.

According to Groeger’s (2000) Cognitive Account of Driving (Section 1.3.3) hazard perception consists of four steps of hazard detection, threat appraisal, action selection, and implementation. The process of dealing with driving hazards is shown to be more complex than just identifying the existence of the potential risk (hazard detection). Responses will depend on the level of threat associated with the risk, and how quickly the driver can select and implement their chosen response. Hazard detection should precede action implementation in the process of responding to hazards. In the current study, the hazard handling condition required drivers to detect a hazard, select an appropriate response, and implement that response; whereas the hazard detection condition cut out the middle step. However, the results of this study show that participants actually had faster response times in the hazard handling condition than in the hazard detection condition. This suggests that when people are driving, the processes of hazard detection, action selection, and action implementation occur more rapidly as they are highly practiced tasks. Responses in the hazard detection task require a more unusual action and this may provide an explanation for the slower response times. In the hazard detection test, where the response is different to anything encountered previously, it could in fact make the action implementation stage more difficult. It is also possible that drivers feel increased danger (threat appraisal) when in control of the vehicle themselves than when sitting in a more passive manner, and this could increase the urgency of response selection. This provides an explanation as to why a more reliable experience difference was found in the hazard handling condition (significant experience effects in both versions of the test), as experienced drivers should have gained the necessary procedural knowledge of driving to change their behaviour almost automatically upon detection of a hazard, whereas novice drivers have not.

3.5.2 Individual Hazard Types

Although many studies have examined the concept of response time to hazards presented on a screen, few have focused on the specific types of hazard which discriminate effectively between novice and experienced drivers (Crundall et al., 2012). The cognitive model of driving predicts that drivers would view the threat inherent in a hazardous situation differently depending on characteristics of the situation such as level of visibility or speed. Therefore, it would be expected that drivers would respond differently to hazards depending on the individual characteristics of a given hazard scenario. This study aimed to address this issue by focusing in detail on the characteristics of different types of hazardous event. The hazards were separated into events involving other road users, where the actions of other road users cause a hazardous situation to arise (i.e. car emerging, merging traffic, and pedestrian hazards); and hazards involving fixed elements of the traffic environment (bends and traffic lights). Analysis of both response rates and response times showed that participants' behaviour depended both on the category of hazard present (e.g. bend or car emerging) and on the different characteristics of a particular hazard category (e.g. pedestrians with continuous or interrupted visibility, traffic lights with amber onset at different times).

A deeper analysis of the individual hazard categories found that hazards involving other road users, particularly pedestrians, provided more consistent discriminatory power between novice and experienced drivers, than hazard categories involving elements of the traffic environment. It had been expected that the visibility of pedestrian events would influence participant's ability to detect and respond to these hazards. However, this did not appear to be the case when both participant age and experience were taken into account. A deeper analysis of traffic light events showed that novice participants responded more slowly than experienced drivers in the hazard detection test to amber onsets occurring in the safe stopping zone. There were no differences between the groups in the other amber onset zones, and no differences in response times emerged in the hazard handling condition. The fact that different results emerged in the two tests depending on the characteristics of the traffic light events highlights the importance of taking individual hazards into account in evaluating hazard responses.

3.5.3 Summary and Conclusions

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Novice drivers will signal the presence of hazards more slowly than experienced drivers in an immersive simulated environment
- Hypothesis 2: Novice drivers will respond more slowly than experienced drivers in a hazard handling test, which requires drivers to change their actual driving behaviour in response to hazards.
- Hypothesis 3: The benefits of experience will vary across hazards, providing a better understanding of the threat appraisal process in hazard responding. Based on the results emerging in Chapter 2, it is anticipated that hazards involving other road users (pedestrians, car emerging, and merging traffic events) will provide better discrimination than hazards involving elements of the environment (bends, traffic lights).
- Hypothesis 4: Participants will make fewer responses to control variables than to hazardous variables.

- Hypothesis 5: The Driving Theory Test, as a measure of a driver’s declarative knowledge, will be significantly related to hazard detection skill, which also appears to tap into declarative knowledge of driving.
- Hypothesis 6: The Driving Theory Test, as a measure of a driver’s declarative knowledge, will not be significantly related to performance on the hazard handling test, a measure of a drivers’ procedural skill.
- Hypothesis 7: The results obtained in version one of the hazard detection and hazard handling tests will be replicated using version two.

The results of this study provide support for Hypothesis 1 and Hypothesis 2 by showing that novice drivers respond more slowly than experienced drivers both when in control of the vehicle themselves, and when signalling the presence of hazards in a hazard detection test.

There is also partial support for Hypothesis 3. It would appear that pedestrian hazards provide the best discrimination between novice and experienced groups. Hazards involving other vehicles were also found to discriminate between experience groups, although this happened less consistently than for the pedestrian hazards.

Correlations between the driver theory test, hazard detection and hazard handling tests signify that what is being measured in a hazard handling test, requiring driving response selection and implementation, is different to what is being measured in a hazard detection test requiring a pre-established discrete response to the presence of a hazard. This provides support for Hypothesis 5 and 6. It would appear that for novice drivers, both the driver theory test and the hazard detection test focus on declarative knowledge of driving, whereas the hazard handling test does not.

Finally, the second versions of the hazard handling test succeeded in replicating the findings obtained in the first version, suggesting a consistent measure of hazard handling skill, thus providing support for Hypothesis 7. This provides evidence that the novice-experienced difference emerging in the hazard handling test is a reliable one.

Overall, the results highlight the importance of separating out the process of detecting and handling individual hazards to provide a deeper and more textured understanding of where novice-related deficits in hazard responding ability lie. It would appear that novice drivers are more dependent on their declarative knowledge of hazards than experienced drivers, and this would appear to be particularly apparent in responding patterns to hazards involving other road users.

4 Speed and Distance Training

4.1 Introduction

The evaluation of vehicle speed, inter-vehicle distances, and distances to traffic signs and other hazards are crucial skills which require constant updating during driving. Manoeuvres such as braking, obstacle avoidance and overtaking are all based on such skills (Kemeny & Panerai, 2003), and require a knowledge of relative, if not absolute, speed and distance.

4.1.1 Speed

Speed is obviously an important factor in road safety, affecting both the risk and the severity of crashes (Aarts & Van Schagen, 2006; Fuller et al., 2006) It is estimated that speed was a contributing factor in between 28% and 30% of fatalities in the U.K., and in 31% of road fatalities in the U.S. between 1996 and 2003 (see Fuller et al., 2009). It has been found that young drivers in particular, are over-represented in speed-related crashes (Clarke, Ward, & Truman, 2005; McKnight & McKnight, 2003; OECD, 2006). In spite of the evidence showing speed as a causal factor in many road accidents, it appears that drivers have very little awareness of their speed patterns while driving, with research by Walton and Bathurst (1998) showing that between 85% and 90% of drivers claimed to drive more slowly than the “average driver”. Milosević and Milić (1990) conducted a study where drivers who had just negotiated a bend were stopped and asked how fast they thought they were travelling and whether or not they had looked at their speedometer. They found that about 90% drivers had not checked their speedometer and that in general participants were inclined to underestimate their speed. This provides an empirical example of drivers’ lack of judgement skills when it comes to evaluating their speed.

Although speed information is prominently displayed in all vehicles, drivers’ eyes are focused outside of the car for the majority of driving time (Groeger, 2000; Recarte & Nunes, 1996). Therefore, it is important to gain an understanding of mechanisms by which drivers perceive and understand their speed, along with establishing methods by which to train speed perception skill more effectively. Recarte, Nunes and colleagues have addressed the issue of speed perception, looking at speed estimation and production in closed track, secondary road, and highway situations (Conchillo, Recarte, Nunes, & Ruiz, 2006; Recarte & Nunes, 1996). Across two studies Recarte and Nunes (1996) distinguished between speed estimation and speed production while driving on a closed track. Participants were exposed to speeds of 60kph, 80kph, 100kph, and 120kph on both straight and curved track. Results showed that participants generally under-estimated their speed by approximately 13 kilometres per hour. This error decreased with increasing speed i.e. participants were more accurate in their estimations of higher speeds. Participants underestimated less after accelerating than after decelerating, i.e. the same speeds were estimated as being higher when coming from previous lower speeds than from higher speeds, although this effect disappeared in the second study when only curved segments of road were used. When participants were given control of an accelerator and brake pedal and asked to adjust to a certain speed (60kph, 80kph, 100kph, 120kph) from a speed either 20kph above or below the target (set by the experimenter), participants over-adjusted by approximately 6 kilometres per hour, and once again the rate of error decreased with increasing speed. The only exception occurred when participants were asked to increase their speed from 100kph to 120kph, where they under-adjusted by 7.6kph (i.e. they reached 112.4kph). Over-adjustment decreased systematically as speed increased. In addition, it appeared that adjustment errors were smaller when participant were asked to produce a certain speed after accelerating rather than decelerating i.e. participants decelerated less than they had accelerated for the same difference in absolute value between previous speed and target speed. Although there were no significant differences between novice and experienced drivers, non-drivers made larger errors in speed adjustments than either of the driving groups. There was a strong negative correlation between speed estimations and productions for individual participants i.e. participants who underestimated more, adjusted to higher levels of speed. Although the authors interpreted the results as showing that estimations and productions of speed occur through a common cognitive process, differences exist in the magnitude of the errors – the over-adjustment errors were smaller in absolute value than the underestimation errors. In addition, an analysis by Groeger (2000) in which the correlation between verbal estimates and produced speeds was analysed for each subject separately and then averaged, found that the relationship between verbal and production estimates are still correlated but this correlation only accounts for approximately 10% of the shared variance between the two estimates. Verbal estimates were most strongly correlated with initial speed presented, rather than target speed, whereas speed productions were more highly correlated with target speed. Thus, it would appear that although estimations and productions of speed are related, they are also influenced by different variables.

In Conchillo et al.'s (2006) study novice and experienced drivers were exposed as passengers to a series of different speeds on both a closed track and an open road. The speeds ranged from 40kph to 120kph and were reached either after a deceleration process following a previous higher speed, or by an acceleration process from a previous lower speed, similar to Recarte and Nunes (1996). A general pattern of under-estimation occurred across all speeds on both the closed track and the open road, although the mean error was higher for the open road. Unlike Recarte and Nunes (1996), there was no significant effect of speed value, although there was a tendency for errors to decrease with increasing speeds on the closed track and to increase with increasing speed on the open road. The error rate on the closed track was in the same direction as the Recarte and Nunes (1996) study but the magnitude was lower (-1.90kph vs. -14.8kph). The two experiments were equivalent except for one condition: the previous presentation of two standard stimuli (70kph and 100kph) before the estimation task in Conchillo et al.'s (2006) study. This suggests that practice may have led to increased understanding of higher speeds. An analysis of the different types of open road shows that the magnitude of error was higher on the highway than on the secondary road and only on the highway were the effects of increases in speed opposite to that of the closed track. The authors suggest that this effect may be due to a higher density of parallel traffic on the highway than on the secondary road. More recent research by Recarte and Nunes (2002) has found that drivers tend to drive approximately 10kph faster when there are no speed restrictions than when there are restrictions. However, when a secondary mental task (e.g. word generation) is introduced participants speed actually increased in the restricted speed condition but not in the free speed condition.

Groeger, Carsten, Blana, and Jamson (1999) designed a simulator-based study which used a similar methodology to Recarte and colleagues. In a simulated test, they asked drivers firstly to estimate their current speed and then to "double" or "halve" their current speed. Once again, the results showed that speed estimations were affected by previous speed, with participants making lower estimations after deceleration, and higher estimations after acceleration. Drivers watched a stable featureless scene for several seconds between trials, thus limiting the impact of previous impressions of motion, and the speed within a trial was constant until the driver chose to accelerate or decelerate. When participants were asked to halve their current speed they failed to reduce their speed sufficiently, and when asked to double their current speed they did not increase speed sufficiently. Speed estimation and production was better with visual information alone than with sound alone, highlighting the importance of auditory information on speed evaluation. When the adjustments made in this study were compared to those made in the Recarte and Nunes (1996) study, the pattern which emerged was remarkably similar (Groeger, 2000), suggesting that this pattern of under-estimating speed is quite consistent and replicable in both naturalistic and simulated driving environments.

Mourant, Ahmad, Jaeger, and Lin (2007) asked participants to produce speeds of either 30 miles per hour (48.2kph) or 60 miles per hour (96.6kph) in a simulator experiment where they manipulated the levels of optic flow. In the low optic flow condition the environment was featureless. In the high optic flow condition, trees lined the side of the road. Their results showed that participants greatly over-adjusted vehicle speed when attempting to produce a velocity of 30mph. The magnitude of average error reached as high as 20mph over the target velocity. When the target velocity was 60mph, the subjects produced an average velocity of 61.7mph. Although it reached significance, the difference in estimations between low and high optical flow conditions was only 2.4mph. The authors conclude that the reason for this small difference may be that participants were using lane markings to help produce the requested velocity in the low optical flow condition and that the addition of trees may have added only a nominal amount to their perception of the amount of optic flow used by a driver. These findings provide added support, in a different simulated environment, for Recarte and Nunes (1996) results. However, there was no analysis of the impact of previous acceleration or deceleration in the Mourant et al. (2007) study. In addition, it is not clear as to whether there was a break between trials or whether participants were constantly changing between the two speeds.

The results reported above show that people rely on relative rather than absolute information regarding speed (Groeger, 2000). It would appear that drivers underestimate their speed and over-adjust when asked to produce changes. In addition, drivers seem to make more errors when decreasing to a target speed than when accelerating. However, none of these studies have developed training procedures which aim to improve drivers' estimations and understanding of their speed. In addition, the importance of visual cues are relatively unknown, although Groeger et al. (1999) found that speed estimation was better with visual information alone than with sound alone, and Mourant et al. (2007) found little effect of optical flow on speed productions.

4.1.2 Distance

While driving, one is constantly estimating and evaluating distances, although this may not be a conscious process. Tasks such as evaluating headway, overtaking, and coming to a stop at traffic lights or stop signs all involve an awareness of safe distances (Baumberger, Flückiger, Paquette, Bergeron, & Delorme, 2005; Groeger, 2000). However, despite the importance of distance perception in traffic safety, the mechanisms of distance perception have rarely been looked at in a driving context.

There are many possible methods that can be used to assess a person's perception of distance. The conceptually simplest approach is to have people make verbal estimates of the distance between themselves and a target location; however numerous studies have shown that verbal reports are generally less accurate than action based metrics (Interrante, Ries, & Anderson, 2006). In tasks of visually directed action, the observer views a target within the immediate environment and then, usually blindfolded, the participant attempts to demonstrate knowledge of distance by walking as far as the object (Loomis, Silva, Philbeck, & Fukusima, 1996). Although some research on distance perception while walking has shown that estimates of egocentric distances (i.e. the distance from the participant to an external object) are often underestimated in both real and virtual environments (e.g. Plumert, Kearney, Cremer, & Recker, 2005; Richardson & Waller, 2005), other studies have shown that people are quite accurate in indicating the location of target distances (Loomis et al., 1996), though many of these studies cover very small distances (e.g. 4m to 15m in the Loomis et al. study). It would appear that people's underestimations of distance increase as physical distance increases. Plumert et al. (2005) measured distance evaluation in real and virtual environments by providing participants with a stopwatch and asking them to start the stopwatch when they imagined starting to walk and to stop the stopwatch when they imagined reaching a target distance point. Distances ranged from 20 to 120 feet and a baseline measure of walking speed was taken prior to the actual experiment. Across both environments, participants consistently underestimated distances of 60ft and beyond. When participants were blindfolded they consistently underestimated distances of 80ft and beyond. However, this measure of distance incorporates an element of time and thus may not provide an accurate assessment of distance evaluation but rather an interpretation of imagined speed and distance.

A small number of studies have looked at distance estimation while driving, with the main focus being on headway distance and on how drivers maintain this in different light conditions (e.g. Castro, Martínez, Tornay, Fernández, & Martos, 2005; Van der Hulst, Rothengatter, & Meijman, 1999). Van der Hulst et al. (1999) found that when visibility was reduced due to simulated fog; drivers maintained a larger distance between them and the car ahead of them. Cavallo, Colomb, and Doré (2001) also explored the perception of vehicle distance in foggy conditions. Participants were asked to make verbal estimations of the distance to a simulated vehicle in front of them when different rear-end fog-lights were used (distances ranged from 8m to 28m). Participants over-estimated all distances in both clear and foggy conditions, with higher overestimations in foggy conditions. Estimations of distance rose faster than actual distance and the relationship between estimated and actual distance was best described using a power function. Castro et al. (2005) found that the level of horizontal separation between the headlights of oncoming cars affected participants' distance estimations; with participants overestimating the distance when the headlights were farther apart and underestimating the distance when the lights were close together. Participants tended to underestimate short (60-240m) and long distances (620-870m) and slightly overestimate medium distances (320-510m).

Baumberger et al. (2005) conducted a driving simulator experiment to evaluate participants ability to gauge driving distances. Two cars were positioned in the lane to the right of the driver at a distance of either 34.5m or 54.5m apart. These vehicles were either motionless or moving at 40kph or 60kph. Participants were asked to bisect the distance, by positioning the front of their vehicle at mid-distance between the two cars, or to position the front of their vehicle abreast with the furthest away of the two vehicles. The target cars disappeared from the visual field before the final adjustment was required. Results indicated that participants underestimated distances in both alignment tasks but that the error was significantly higher in the bisection task. Participants were significantly better at making distance judgements when the target cars were motionless than when they were moving. In addition, in the bisection task, participants were more accurate when the cars were moving at 60kph rather than 40kph; and when the distance between the two vehicles was 40m rather than 60m. The authors argue that the improvement in performance with an increase in speed and a decrease in distance was a result of drivers belief that the slower the speed and the greater the distance, the less they need to be accurate. However, as with studies on walking distances, the disappearance of the visual cues means that participants have to rely on their memory of target locations and this may be confounding the distance measure. This study, when taken with the previous literature on walking distances, suggests that people are inclined to underestimate distances, at least while visual information regarding the distance is obscured. One flaw with these studies is that they are relying on people's memories for the location of the initial target, leading to a potential confounding of vision and ability to understand distances.

Groeger et al. (1999) conducted a simulator-based driving study where participants were asked to provide verbal estimates of the distance of a familiar object (red London bus) and an unfamiliar object (red box). They were then asked either to move a smaller object to the point half way between themselves and the target or to move themselves to the halfway point. Distances ranged from 5m to 450 metres. Similar to the research of Plumert et al. (2005) and Baumberger et al. (2005), participants were inclined to under-estimate distances when making verbal estimates, with estimates being more accurate for distances under 150 metres than those beyond. For the bisection task, accuracy was higher when the participant themselves moved, than when a marker object was moved to bisect the distance. For distances longer than 50 metres, accuracy of bisections decreased as distance increased, with participants moving further than necessary. As with the research on speed evaluation, it would appear that drivers tend to under-estimate and over-produce when asked to evaluate driving distances.

The limited results available suggest that, similar to speed, drivers are not making absolute evaluations of distance, but instead are using some relative appraisals. Although driving researchers have examined distance estimation in complex conditions, little effort has been made to evaluate the accuracy of distance judgements in simpler driving situations. In addition, there have been few attempts to understand the relationship between the estimation and the production of distance. This knowledge is necessary to provide an understanding of the mechanisms underlying distance evaluations while driving.

4.1.3 Designing Training

Research has suggested that practice conditions that promote additional cognitive effort are most effective for learning (Lee, Swinnen, & Serrien, 1994; cited in Wulf & Shea, 2002). Extensive practice is an essential prerequisite for developing expertise in any task (Groeger, 2000). Much research using simple laboratory tasks suggests that randomly ordering training tasks, thus requiring more effort, exercises retrieval processes that later facilitate test performance (e.g. Savion-Lemieux & Penhune, 2010; Shea & Morgan, 1979; Wulf & Schmidt, 1997). In addition, it has generally been found that distributed practice leads to slower improvements in performance during training than massed practice, but leads to better retention and transfer after training (Bloom & Shuell, 1981; Groeger, 2000). Therefore, for the purposes of this study, it was decided to hold the training over consecutive days to enable consolidation of skills, a process which has sometimes been linked with sleep (Savion-Lemieux & Penhune, 2010). In addition, in order to capitalise on effects of distributed practice, the order of events was randomised to try to improve retention of learning.

Research also suggests that making feedback from training more difficult to use (e.g. by delaying it, or withholding it on some practice trials) can be beneficial for performance as it requires learners to develop their own internal error mechanisms (Wulf & Shea, 2002). The presentation of augmented feedback, or knowledge of results, at the end of a sequence of movements has generally been found to be more successful for motor skill acquisition and retention than concurrent feedback (Groeger, 2000; Newell, 1991; Salmoni, Schmidt, & Walter, 1984). Specific feedback that directs performers to correct responses typically leads to performance improvements and decreased errors during practice, and more rapid acquisition of skills (see Goodman, Wood, & Hendrickx, 2004; Kruger & DeNisi, 1996). However, this type of feedback is not as good for long term retention of learning as there is a danger that performers will become overly reliant on the feedback (Goodman et al., 2004). Summary feedback occurs where feedback about each trial is only given after a certain number of trials have been completed (Wulf & Shea, 2002). This method has been adopted for both training studies, in order to provide participants with information on where improvement is needed without encouraging them to become overly dependent on that feedback.

4.1.4 Study Aim and Research Questions

The purpose of this chapter is to implement a speed and distance training regime modelled on that of Recarte and Nunes (1996). This training aims to develop participants' basic control and vehicle awareness skills.

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Basic vehicle control and perception elements i.e. speed and distance can be improved through simulator based training
- Hypothesis 2: Novice drivers' performance will be worse than that of experienced drivers prior to training, but the improvement observed after training should be greater for novice than experienced drivers (Groeger, 2001).

4.2 Method

Previous studies have found that participants generally underestimate speed, with mixed findings emerging from the distance literature. This study will aim to expand on that research in a simulated driving context, in addition to developing a training regime with the aim of improving drivers' basic vehicle control and perception skills.

4.2.1 Participants

A total of 20 participants volunteered for the study, 10 males and 10 females. The novice drivers had less than two years total driving experience (M=0.59yrs, SD=0.64) with an age range of 17.73 to 50.26 years (M=25.14yrs; SD=2.98). The experienced group had between 5 and 15 years driving experience (M=7.87yrs, SD=2.43) and an age range of 22.17 years to 51.86 years (M=28.85yrs; SD=2.74). The groups differed significantly in terms of experience ($t\ (18)=-9.15$, $p<.001$); but there were no significant age differences ($t(18)=-0.92$, $p=0.37$). All participants completed the study. Participants were recruited through the use of University College Cork's (UCC) student mailing list, advertisements posted around the UCC campus, and through the development of a Facebook profile. All participation was voluntary and informed consent was obtained prior to participation. Participants received €10 payment for each training session they attended.

4.2.2 Apparatus

All of the training took place in UCC's driving simulator. Both the speed and distance training took place in a totally featureless environment (see Figure 29). The speedometer was covered during all training sessions.

Figure 29: Images of featureless environments used in speed and distance drives (speed on left, distance on right)

4.2.3 Design and Procedure

On the first day of training participants filled out informed consent and SSQ forms. They then completed a pre-training hazard handling test (discussed in Chapter 6). After the hazard handling test they were given a 10 minute break while the driving simulator was set up for the next part of the study. All participants completed both speed and distance training, with half of the group doing speed training first and the other half doing distance training first.

For the speed training, participants were seated in the driver's seat and told that when they heard one bell sounding the experimenter would take control of the vehicle using the control computer. The experimenter set the simulation to a certain speed (45kph, 60kph, or 75kph). After 200m the participant was played a previously recorded instruction asking them to provide a verbal estimate of their current speed. Once the estimate was recorded, the participant heard two bells, indicating that control of the pedal was being transferred to them. They were then given a verbal instruction to either increase their speed by 10kph, 20kph, or 40kph; or to decrease their current speed by 10kph, 20kph, or 35kph, and were asked to sound the horn once they felt the target change had been met. This process was then repeated. Each of the estimation speeds was presented six times and each adjustment speed was presented three times in a session. The order of the estimation speeds remained the same across all studies (six presentations of 45kph, six presentations of 60kph, and six presentations of 75kph). The order of the adjustment speeds was counterbalanced across training blocks, with each adjustment speed requested once after each estimation speed. A single training block took approximately 10 minutes to complete, after which participants were provided with summary feedback on their performance. They were shown two graphs, one with the average accuracy of their estimation performance on each of the three estimation speeds, and one with the average accuracy of their performance on each of the requested adjustments. After feedback, participants completed another training block, followed by more feedback.

For the distance training, participants were seated in the driving simulator and given instructions to estimate the distance to a stop sign that was located some distance in front of them. The distances were 10m, 20m, 25m, 50m, 65m, 100m, 130m, and 220m. Once the estimated distance was recorded, participants were then given a pre-recorded instruction to drive to the point which they felt was half way to the sign and to sound the horn once they had done so. Once they had sounded the horn, another pre-recorded message told them to come to a stop after the sign and the process was repeated again. Each distance was presented twice in each training block and the order was counterbalanced. The training blocks took approximately 10 minutes to complete and, similar to the speed training, participants were given summary feedback at the end of each block. The feedback consisted of two graphs, one of which provided information on the accuracy of estimations for short, medium, and long distances; and the other provided information on the accuracy of adjustments for short, medium, and long distances. A second block of training was then completed, followed by a second feedback session.

Training took place over four days, with speed and distance practice occurring in the same order each day. Participants were given a 5 minute break between the speed and distance training sessions. After the last training session, participants once again completed the hazard handling test (see Chapter 6).

The dependent variables were:

- Speed estimation accuracy
- Speed production accuracy
- Distance estimation accuracy
- Distance production accuracy

All four dependent variables were evaluated as a proportion of the target value (e.g. a score of 1 indicated that the participants had correctly estimated the speed, lower scores indicated under-estimation, and higher scores and over-estimation)

The independent variables were as follows:

- Experience Group (between groups)
- Training Day
- Speed Zone for estimation trials: 45kph, 60kph, 75kph
- Speed Change requested for production trials: increase 10kph, increase 20kph, increase 40kph, decrease 10kph, decrease 20kph, decrease 35kph
- Distance for estimation trials: 10m, 20m, 25m, 50m, 65m, 100m, 130m, and 220m
- Distance for production trials: 5m, 10m, 12.5m, 25m, 32.5m, 50m, 65m, and 110m

4.3 Results

This section provides a series of analyses of variance to explore the pattern of speed and distance evaluations.

4.3.1 Speed Estimation

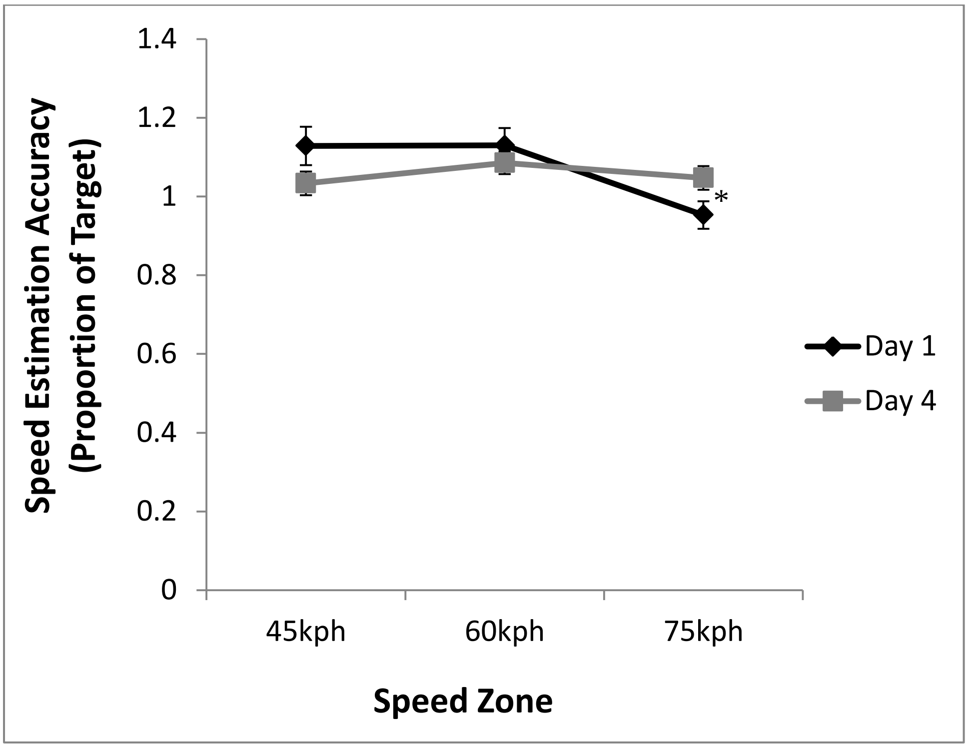
To begin, the performance of novice and experienced drivers on day one and day four of training was compared (see Table 45). Speed estimation accuracy was evaluated as a proportion of the target speed (i.e. a score of 1 indicated that the participant had correctly estimated the speed, lower scores indicated an under-estimation and higher scores an over-estimation). A four-way between-within groups' analysis of variance was conducted. The between groups variable was experience group, and the within groups variables were training day, feedback status and speed.

Table 45: Effects of experience group, training day, feedback status, and speed on the accuracy of speed estimations as a proportion of target speed

	Df	F	p	η_p^2
Experience Group	1,18	0.96	0.34	0.05
Training Day	1,18	0.12	0.73	0.01
Pre/Post Feedback	1,18	1.03	0.32	0.05
Speed Zone	2,17	10.76	<0.001	0.37
Training Day * Speed	2,17	13.50	<0.001	0.43
Training Day * Experience	1,18	0.04	0.84	0.002
Feedback * Experience	1,18	0.21	0.65	0.01
Speed * Experience	2,17	0.67	0.52	0.04

The results show that there was no significant difference in the accuracy of speed estimates between the first and the last day of training ($F(1,18)=0.12$, $p=0.73$), with participants overestimating their speed by a similar, albeit small, proportion on day one ($M=1.07$, $SE=0.04$) and day four ($M=1.06$, $SE=0.03$). There was also no effect of driving experience on estimates of speed ($F(1,18)=0.96$, $p=0.34$), with novice ($M=1.04$, $SE=0.03$) and experienced drivers ($M=1.09$, $SE=0.03$) over-estimating their speed by a similar proportion.

Speed-zone had a large significant effect on participants estimates of speed ($F(2,17)=10.76$, $p<0.001$; $\eta_p^2=0.37$), with participants making significantly more accurate estimates when travelling at 75kph than at other speeds. There was also a large, significant interaction between training day and speed zone ($F(2,17)=13.50$, $p<0.001$, $\eta_p^2=0.43$), displayed in Figure 30.



*p<0.05

Figure 30: Interaction between training day and speed zone on the accuracy of speed estimates as a proportion of the target speed (mean values, error bars represent standard error)

A paired samples t-test shows that participants' estimates in the 75kph zone differed significantly between day one and day four ($t(19)=-2.26$, $p<0.05$, $|d|=0.66$). Participants under-estimated their speed in the 75kph zone on day one ($M=0.95$, $SE=0.03$) and over-estimated by a similar proportion on day four ($M=1.05$, $SE=0.03$). There were no significant changes in the accuracy of estimates in either the 45kph ($t(19)=1.83$, $p=0.08$, $|d|=0.52$) or the 60kph ($t(19)=0.90$, $p=0.38$, $|d|=0.27$) speed zones.

It is interesting to note that unlike previous studies, participants in this study were inclined to over-estimate their speeds, and this did not change much after training. As with Recarte and Nunes (1996) study, there were no differences in the abilities of novice and experienced drivers to estimate speed.

4.3.2 Speed Production

Results of a five-way between-within groups' analysis of variance on the accuracy of speed productions are presented in Table 46. The between groups variable was experience group, and the within groups variables were training day, feedback status (pre/post training), preceding speed, acceleration direction required (increase/decrease speed), and the target adjustment amount (10kph, 20kph or 35/40kph). Once again the accuracy of speed productions is presented as a proportion of the target speed.

Table 46: Effect of experience group, training day, feedback status, preceding speed, acceleration direction, and target adjustment on the accuracy of speed productions as a proportion of target speed

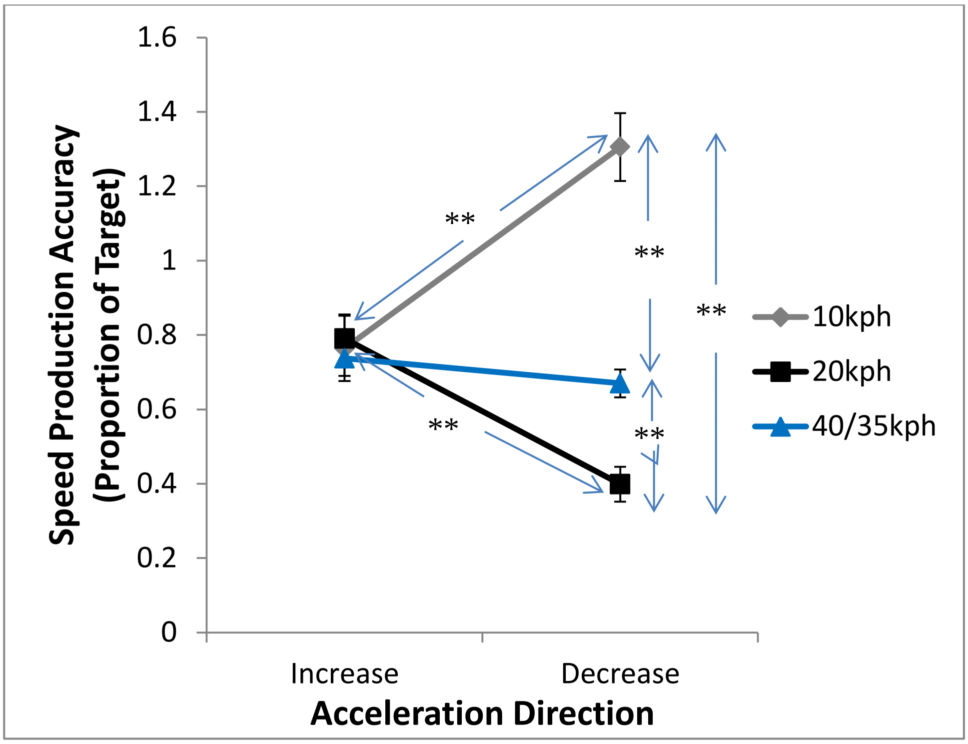
	Df	F	p	η_p^2
Experience Group	1,18	0.58	0.49	0.03
Training Day	1,18	2.56	0.13	0.12
Pre/Post Feedback	1,18	1.83	0.19	0.09
Preceding Speed	2,17	7.37	0.002	0.29
Increase/Decrease Speed	1,18	0.10	0.75	0.006
Target Adjustment	2,17	72.79	<0.001	0.80
Day * Feedback Trial	1,18	4.65	0.05	0.21
Day * Preceding Speed	2,17	4.22	0.02	0.19
Preceding Speed * Inc/Dec	2,17	37.70	<0.001	0.68
Preceding Speed * Target	4,15	2.74	0.04	0.13
Inc/Dec * Target	2,17	55.33	<0.001	0.76
Day * Experience	1,18	0.03	0.86	0.002
Feedback * Experience	1,18	1.71	0.21	0.09
Preceding Speed * Experience	2,17	0.73	0.49	0.04
Inc/Dec * Experience	1,18	0.01	0.95	<0.001
Target * Experience	2,17	0.08	0.92	0.01

Experience group did not have a significant effect on the accuracy of speed adjustments ($F(1,18)=0.58$, $p=0.49$), with both groups tending not to adjust their speed enough. Novice drivers adjusted their speed by an average proportion of 0.75 of the target speed (SE=0.05) and experienced drivers adjusted by an average proportion of 0.81 of the target speed (SE=0.06).

There was no significant improvement in the accuracy of speed adjustments between the first and last day of training ($F(1,18)=2.56$, $p=0.13$). However, there were a number of significant interaction effects involving training day and these are explored further in Figure 34 and Figure 35 below.

Preceding speed had a large, significant effect on the accuracy of speed productions ($F(2,17)=7.37$, $p<0.01$, $\eta_p^2=0.29$), which is further explored in Figure 32, Figure 33, and Figure 34 below. In addition, the target speed had a significant effect on adjustment accuracy ($F(2,17)=72.78$, $p<0.001$, $\eta_p^2=0.80$), with participants showing significantly more accuracy when asked to produce a speed change of 10kph (M=1.04, SE=0.06), than when asked to change by 20kph (M=0.60, SE=0.04) or 35/40kph (M=0.70, SE=0.03). Participants were significantly less accurate when asked to adjust their speed by 40kph/35kph than when adjusting by 10kph or 20kph. However, interaction effects show that this is most likely a result of participants' under-adjusting 10kph changes in some situations and over-adjusting in others (see Figure 31).

There were a number of significant interaction effects. Firstly there was a large significant interaction between target speed adjustment and whether participants were accelerating or decelerating ($F(2,17)=55.33$, $p<0.001$, $\eta_p^2=0.76$).

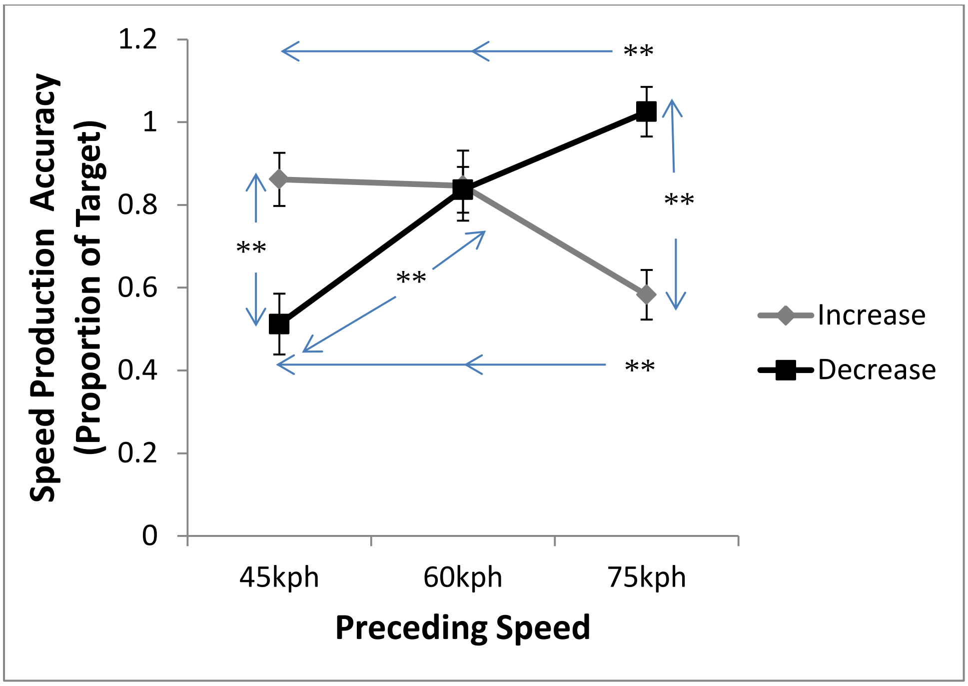


**p<0.01

Figure 31: Interaction between acceleration direction and target speed change on the accuracy of speed productions as a proportion of target speed (mean values, error bars represent standard error)

A within-groups analysis of variance shows that the accuracy of participant's speed productions did not differ significantly across target speeds when participants were asked to increase speed ($F(2,18)=0.53$, $p=0.60$, $\eta_p^2=0.03$). However, when participants were asked to decrease their speed, the accuracy of production depended on the requested adjustment amount ($F(2,18)=62.19$, $p<0.001$, $\eta_p^2=0.77$). This shows that the main effect of over-adjustment when decreasing speed is most likely caused by participants over-adjusting when asked to make a change of 10kph, a change much smaller than those used by either Groeger et al. (1999) or Recarte and Nunes (1996). Participants did not change their speed sufficiently when decreasing by either 20kph or 35kph.

There was a large, significant interaction between the preceding speed and the type of adjustment requested (i.e. increase or decrease speed) ($F(2,17)=37.70$, $p<0.001$, $\eta_p^2=0.68$). This interaction is presented in Figure 32 below.

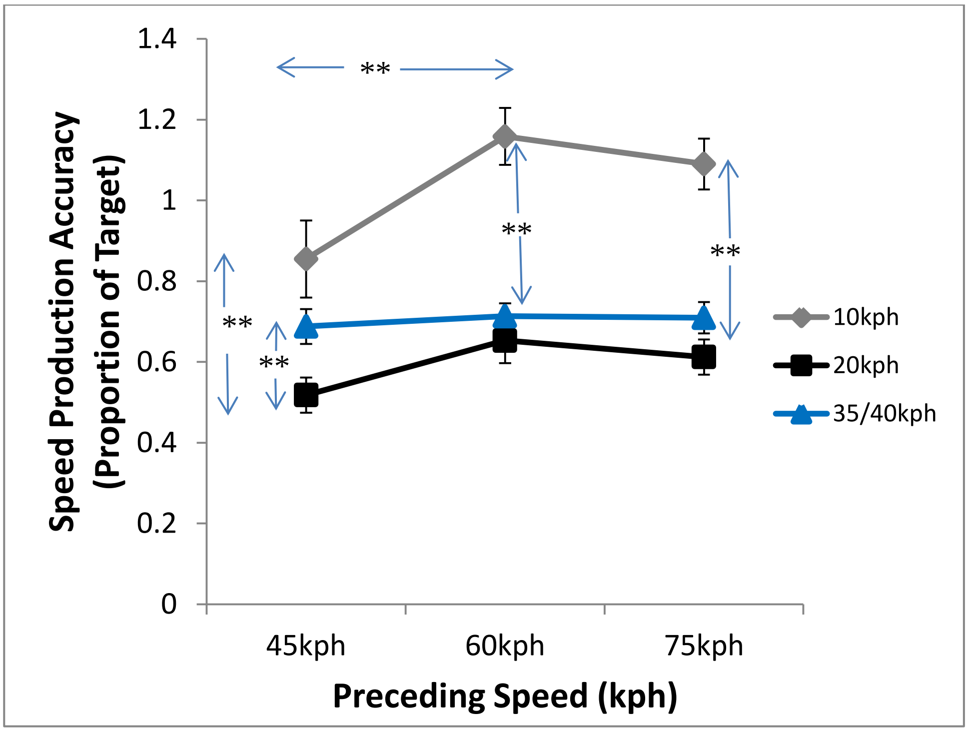


**p<0.01

Figure 32: Interaction between preceding speed and acceleration direction on the accuracy of speed productions as a proportion of target speed (mean values, error bars represent standard error)

Paired sample t-tests show that the difference between increasing and decreasing speed reached significance in both the 45kph ($t(19)=3.59$, $p=0.002$, $|d|=1.14$) and the 75kph zone ($t(19)=-4.68$, $p<0.001$, $|d|=1.68$). Participants made more accurate adjustments when decreasing from a speed of 75kph than when increasing from the same speed. The opposite was true when adjusting speed from 45kph. When increasing speed, participants were significantly less accurate when making a speed adjustment from 75kph than when adjusting from 45kph or 60kph ($F(2,18)=14.49$, $p<0.001$, $\eta_p^2=0.43$). Accuracy of decreasing adjustments differed significantly across all three starting speeds ($F(2,18)=31.32$, $p<0.001$, $\eta_p^2=0.62$). Participants showed significantly more accuracy when decreasing from 75kph than from 60kph ($MD=0.19$, $SE=0.05$, $p<0.01$) or 45kph ($MD=0.51$, $SE=0.08$, $p<0.001$), and were significantly more accurate at decreasing from 60kph than 45kph ($MD=0.33$, $SE=0.06$, $p<0.001$). These findings provide further evidence that drivers' ability to evaluate changes in their speed behaviour is dependent on their starting speed. They are more accurate when increasing from lower speeds and decreasing from higher speeds.

Preceding speed also interacted with target speed change to affect speed production ($F(4,15)=2.74$, $p<0.05$, $\eta_p^2=0.13$; see Figure 33).



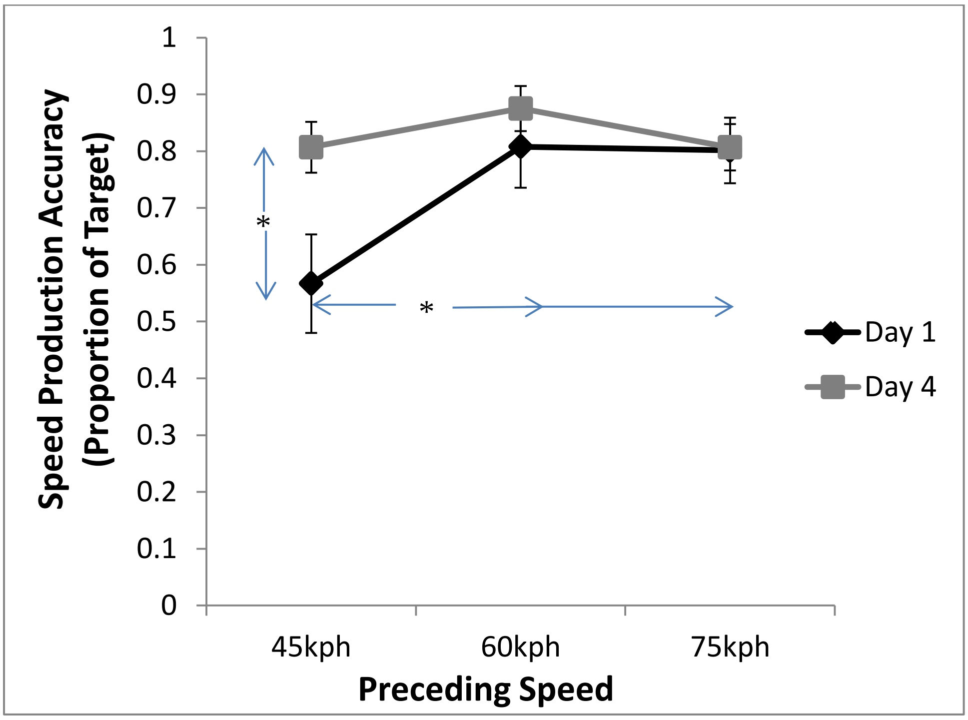
**p<0.01

Figure 33: Interaction between preceding speed and target adjustment amount on the accuracy of speed productions as a proportion of target speed (mean values, error bars represent standard error)

A number of within-groups analyses of variance show that the only speed adjustment which differed significantly depending on the preceding speed was 10kph ($F(2,18)=5.63$, $p<0.01$, $\eta_p^2=0.23$), with participants displaying significantly different response patterns when adjusting from 45kph and 60kph (MD=0.30, SE=0.08, $p<0.01$). The accuracy of 20kph and35/40kph adjustments in speed did not differ across starting speeds.

A within-subjects analysis of variance shows a significant effect of target speed when adjusting from 45kph ($F(2,18)=9.90$, $p<0.001$, $\eta_p^2=0.34$), with participants showing less accuracy in their adjustments of 20kph from this speed than adjustments of 10kph (MD=0.34, SE=0.09, $p<0.01$), or 35/40kph (MD=0.17, SE=0.04, $p<0.001$). Target speed also had a significant effect when adjusting from 60kph ($F(2,18)=56.90$, $p<0.001$, $\eta_p^2=0.75$), with a Bonferroni comparison of means showing that participants were inclined to over-adjust when aiming to change their speed by 10kph, whereas they didn't adjust enough when changing their speed by 20kph (MD=0.51, SE=0.06, $p<0.001$) or 40kph (MD=0.45, SE=0.06, $p<0.001$).. Finally, there was a significant effect of target speed adjustment when changing speed from 75kph ($F(2,18)=37.21$, $p<0.001$, $\eta_p^2=0.66$), with participants making significantly more accurate adjustments of 10kph from this speed than 20kph (MD=0.48, SE=0.07, $p<0.001$) or 35/40kph (MD=0.38, SE=0.06, $p<0.001$).

There were two significant interactions involving training day. Firstly, training day interacted with speed preceding any adjustments ($F(2,17)=4.22$, $p<0.05$, $\eta_p^2=0.19$). This interaction is displayed in Figure 34.

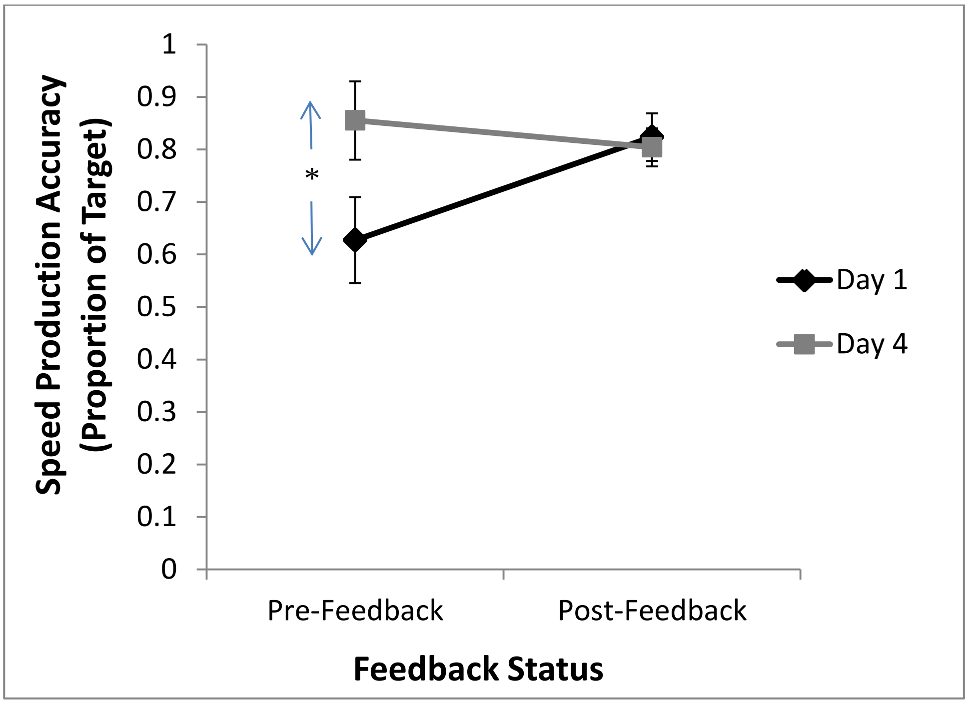


*p<0.05

Figure 34: Interaction between training day and preceding speed on the accuracy of speed productions as a proportion of target speed (mean values, error bars represent standard error)

A within-groups ANOVA shows that preceding speed had a significant effect on the accuracy of speed adjustments on the first day of training ($F(2,18)=8.14$, $p<0.001$, $\eta_p^2=0.30$), but this effect had disappeared by the last day of training ($F(2,18)=1.41$, $p=0.26$, $\eta_p^2=0.07$). In particular, on day one participants showed significantly less accuracy when adjusting from 45kph than when adjusting from 60kph (MD=0.24, SE=0.07, $p<0.01$) or 75kph (MD=0.23, SE=0.08, $p<0.05$). Participants ability to adjust their speed from a starting speed of 45kph improved significantly between day one and day four ($t(19)=-2.50$, $p<0.05$, $|d|=0.78$).

Finally, training day and feedback status interacted to affect speed production accuracy ($F(1,18)=4.65$, $p<0.05$, $\eta_p^2=0.21$; see Figure 35).



*p<0.05

Figure 35: Interaction between training day and feedback status on the accuracy of speed productions as a proportion of target speed (mean values, error bars represent standard error)

There was a significant difference between pre-feedback performance accuracy on day one and day four ($t(19)=-2.40$, $p<0.05$, $|d|=0.79$), with participants making significantly more accurate adjustments prior to feedback on day four. There were no significant differences in post-feedback performance on the two days ($t(19)=0.27$, $p=0.79$, $|d|=0.07$). The difference between pre- and post-feedback performance on day one approached significance ($t(19)=2.03$, $p=0.06$, $|d|=0.43$), but this difference had disappeared by day four ($t(19)=0.95$, $p=0.35$, $|d|=0.27$).

4.3.3 Summary of Speed Results

The results of this study contradict some of the previous findings in the area of speed estimation. Participants tended to over-estimate their speeds, whereas in previous studies participants had under-estimated their speed (Conchillo et al., 2006; Groeger et al., 1999; Mourant et al., 2007; Recarte & Nunes, 1996). Participants were also inclined to under-adjust when asked to change their speed, but this varied according to the target speed adjustment, previous speed, and previous acceleration/deceleration. Participants had more variable performance when decelerating to reach a target speed, and this appeared to depend much more on the previous speed than acceleration behaviour. This supports the previous findings that drivers were less accurate when decreasing than when increasing speed (Groeger et al., 1999; Recarte & Nunes, 1996). Target adjustment amounts were also affected by previous speed, with 10kph changes in particular being affected. Finally, although feedback led to a significant improvement in speed adjustments on the first day of training, this effect had disappeared by the last day, suggesting that the initial feedback led people to develop quite consistent internal measures of their own speed across days. There was no main effect of training day on speed production accuracy, but participants' ability to adjust their speed from an initial speed of 45kph did improve between day one and day four. Training did not lead to any improvements in speed estimation accuracy.

4.3.4 Distance Estimation Accuracy

In the first analysis of participants distance evaluation performance, novice and experienced drivers' accuracy in estimating distance was compared between day one and day four of training. Results of a four way between-within groups ANOVA are presented in Table 47. The between groups variable was experience group and the within groups variables were training day, feedback status (i.e. pre/post feedback), and actual distance to be estimated.

Table 47: Effect of experience group, training day, feedback status, and distance on the accuracy of distance estimation as a proportion of target distance

	Df	F	p	η_p^2
Experience Group	1,18	3.07	0.10	0.15
Training Day	1,18	2.26	0.15	0.11
Pre/Post Feedback	1,18	0.54	0.47	0.03
Actual Distance	8,11	1.97	0.05	0.10
Day * Experience	1,18	2.26	0.15	0.11
Feedback * Experience	1,18	1.51	0.24	0.08
Distance * Experience	8,11	0.92	0.51	0.05

Training day did not have a significant effect on the accuracy of distance estimates ($F(1,18)=2.26$, $p=0.15$). However, an analysis of the mean accuracy shows a large difference between day one ($M=0.71$, $SE=0.09$) and day four ($M=0.90$, $SE=0.08$), and a medium effect size of 0.11. These findings suggest that, with a larger sample size, a significant improvement in accuracy across training days may have occurred.
There was no significant difference between the experience groups in terms of accuracy of distance estimates ($F(1,18)=3.10$, $p=0.10$). However, once again, a look at mean accuracy shows that novice drivers ($M=0.71$, $SE=0.08$) underestimated distances more than experienced drivers ($M=0.90$, $SE=0.08$). As with the training day effect, a large effect size of 0.15 suggests that this may be a meaningful difference.

Target distance was the only variable to have a significant effect on distance estimations ($F(8,11)=1.97$, $p<0.05$, $\eta_p^2=0.10$). As Figure 36 shows, participants underestimated all distances, and appear to have underestimated shorter distances by a greater proportion than long distances, although none of the individual differences reach significance.

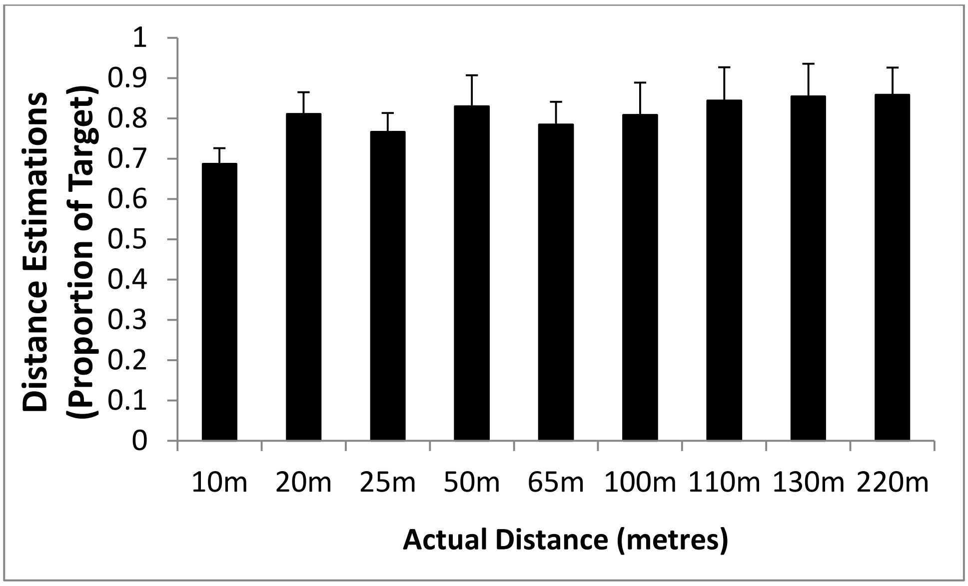


Figure 36: Accuracy of distance estimations as a proportion of target distance (mean values, error bars represent standard error)

This result supports the evidence of Castro et al. (2005) who found that participants under-estimated distances between 60 and 240m.

There were no significant interaction effects.

4.3.5 Distance Production Accuracy

The second analysis of participants' distance evaluations compared novice and experienced drivers' accuracy in distance productions between day one and day four of training. Results of a between-within groups ANOVA are presented in Table 48. The between groups variable was experience group and the within groups variables were training day, feedback status (i.e. pre/post feedback), and actual distance to be produced. Distance productions of 5 metres had to be excluded from the analysis due to a problem with the recording of this distance.

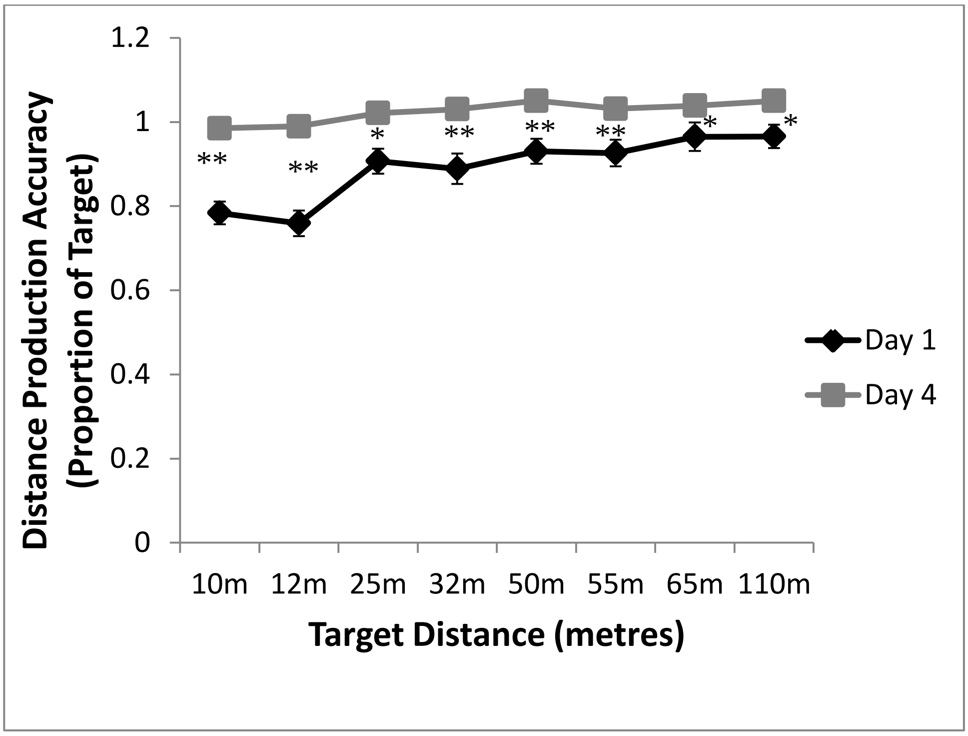
Table 48: Effect of experience group, training day, feedback status, and distance on the accuracy of distance production as a proportion of target distance

	Df	F	p	η_p^2
Experience Group	1,18	0.03	0.86	0.002
Training Day	1,18	29.30	<0.001	0.62
Pre/Post Feedback	1,18	22.65	<0.001	0.56
Target Distance	7,12	17.41	<0.001	0.49
Day * Experience	1,18	3.71	0.07	0.17
Day * Feedback	1,18	11.71	0.003	0.39
Day * Target Distance	7,12	5.96	<0.001	0.25
Feedback * Experience	1,18	0.19	0.67	0.01
Target Distance * Experience	7,12	1.66	0.12	0.09

Training day had a large, significant effect on distance productions ($F(1,18)=29.30$, $p<0.001$, $\eta_p^2=0.62$). Participants made more accurate productions of distance on the last day of training ($M=1.03$, $SE=0.01$) than on the first day ($M=0.89$, $SE=0.03$). Feedback also had a large, significant effect on performance ($F(1,18)=22.65$, $p<0.001$, $\eta_p^2=0.56$), with participants distance adjustment improving significantly from pre-feedback ($M=0.91$, $SE=0.02$) to post-feedback trials ($M=1.00$, $SE=0.02$).

Experience group did not have an effect on the accuracy of distance productions ($F(1,18)=0.03$, $p=0.86$), with novice and experienced drivers both under-adjusting their distance by a similar, albeit small, proportion ($M=0.96$, $SE=0.02$).

Target distance had a large, significant effect on the accuracy of distance productions ($F(7,12)=17.41$, $p<0.001$, $\eta_p^2=0.49$), with participants making significantly more accurate productions of distance at 65m and 110m than at other distances (see Figure 37). There was also a large significant interaction between target distance and training day ($F(7,12)=5.96$, $p<0.001$, $\eta_p^2=0.25$).

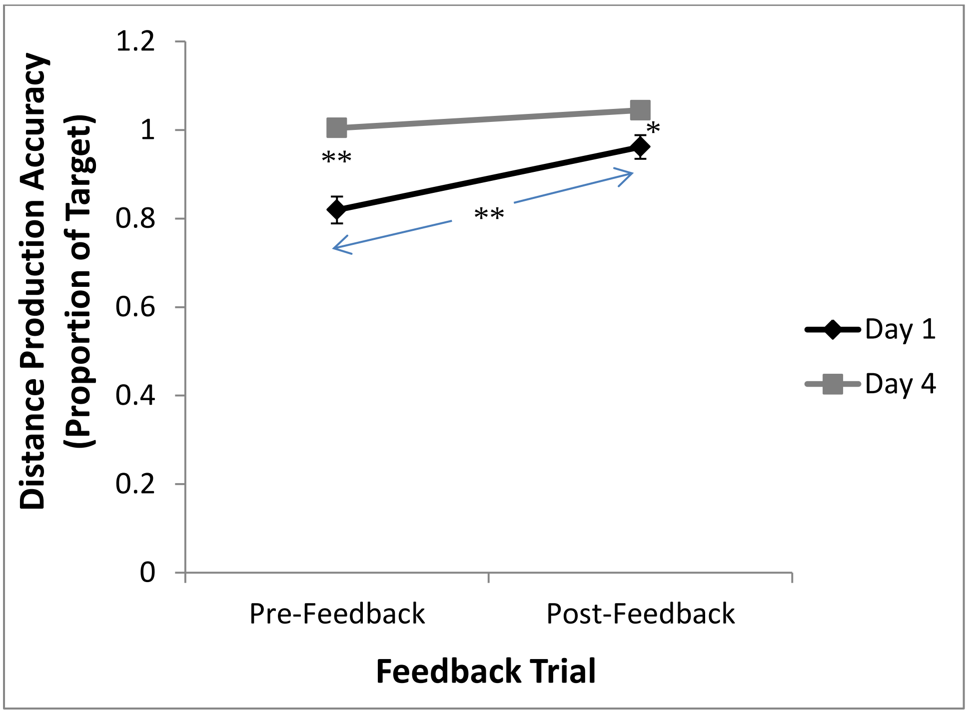


*p<0.05, **p<0.01

Figure 37: Interaction between training day and target distance on the accuracy of distance production as a proportion of target distance (mean values, error bars represent standard error)

Paired samples t-tests show that there was a significant improvement in the production of all target distances between day one and day four ($t(19)<-2.46$, $p<0.05$). A within-groups analysis of variance found that on the first day of training there was a significant difference in the accuracy of production distances ($F(7,13)=21.78$, $p<0.001$, $\eta_p^2=0.53$) with participants showing significantly less accuracy when producing distances of 10m and 12m, than any of the larger distances ($MD>0.11$, $p<0.05$). Although the overall effect of distance on the accuracy of distance productions across target distances remained significant on day four ($F(7,13)=2.25$, $p<0.05$, $\eta_p^2=0.11$), there were no differences between the accuracy of any of the individual distances.

There was also a large significant interaction between training day and feedback status in terms of their effect on distance production accuracy ($F(1,18)=11.71$, $p<0.01$, $\eta_p^2=0.39$). This is presented in Figure 38 below.



*p<0.05, **p<0.01

Figure 38: Interaction between training day and feedback status on the accuracy of distance productions as a proportion of target distance (mean values, error bars represent standard error)

The effect of feedback on day one of training was significant ($t(19)=-7.10$, $p<0.001$, $|d|=1.13$), but by day four this effect had disappeared ($t(19)=-1.48$, $p=0.18$, $|d|=1.25$). There was a significant difference in performance accuracy prior to feedback on the first and last day of training ($t(19)=-6.47$, $p<0.001$, $|d|=1.70$), and this difference in performance accuracy remained on day four, although its effect size had decreased ($t(19)=-2.60$, $p<0.05$, $|d|=0.78$).

4.3.6 Summary of Distance Results

The results of the distance evaluation provide some insight into the manner in which drivers perceive and produce distances while driving. It was found that participants tended to under-estimate distances, and although it did not reach significance, novice drivers seemed to be more susceptible to this misevaluation than experienced drivers. There was also some evidence that training may have led to improved estimations of distance, although once again this failed to reach significance. The results show that training did lead to significant improvements in the production of distances, particularly shorter distances, with participants making considerably smaller errors on the last day of training than the first. Feedback on performance also appeared to have a greater impact on distance productions on the first day of training than on the last.

4.4 Discussion

The purpose of this study was to design and evaluate a training regime aimed at improving drivers' ability to understand the most basic elements of driving behaviour i.e. speed and distance perception and control. Results suggest that drivers have a better awareness of distance information than speed information, and that their knowledge and productions of distance can be further improved through training.

Training was successful in improving the accuracy of drivers' productions of distance, particularly for distances of less than 12 metres. The feedback received was also successful in improving participants' productions of distance, particularly on the first day of training. There was some evidence that estimations of distance could also be improved with training, although a larger sample size would be needed to explore this finding further. Although overall speed production did not improve across training days, participants' ability to adjust their speed from an initial speed of 45kph did improve between day one and day four. In addition, it appeared that feedback was successful in improving performance on the first day of training but this impact had disappeared by the last day. Training did not seem to improve drivers' estimations of speed. Similar to previous research, there were no significant differences between novice and experienced drivers perceptions of speed (Recarte & Nunes, 1996). There was, however, an indication that novice drivers might have poorer distance perception skills than experienced drivers as there was a large non-significant trend of novice drivers under-estimating distances by a greater amount than experienced drivers, although there were no significant differences between the groups when producing distances.

The results of this study contradict some of the previous findings in the area of speed estimation. Participants tended to over-estimate their speeds, whereas in previous studies participants had under-estimated their speed (Conchillo et al., 2006; Groeger et al., 1999; Mourant et al., 2007; Recarte & Nunes, 1996). This may have been a result of the featureless environment used in this study which prevented participants from using any external cues to judge their speed. Although Mourant et al. (2007) found very little difference in speed productions in conditions of high and low optic flow, it would appear from this study that the lack of optic flow may have led to drivers thinking they were travelling faster than they actually are, a finding that did not emerge in previous studies with higher optic flow. As with Groeger et al.'s (1999) study, it appeared that participants had more difficulty in decelerating a target amount than in accelerating the same amount. In addition, participants seemed to be consistent in adjustments of 20kph and 40kph made across trials, suggesting some consistent schema for making changes in speed over a certain amount. The accuracy of 10kph changes was very variable, and seemed to be particularly affected by previous speeds, suggesting that drivers have particular difficulty interpreting small changes in speed.

There had been very little previous research into how drivers perceive and produce distances. The results of this study show that drivers tend to under-estimate and under-produce distances to an object, but that distance production in particular can be improved through training. These results suggest that drivers initially seem to rely on relative rather than absolute judgements of distance, which are usually shorter than reality. However, it appears that these judgements can be improved with training, and that drivers can develop quite an accurate understanding of absolute distances.

4.4.1 Summary and Conclusions

The specific research hypotheses being addressed are as follows:

- Hypothesis 1: Basic vehicle control and perception elements i.e. speed and distance can be improved through simulator based training
- Hypothesis 2: Novice drivers performance will be worse than that of experienced drivers prior to training but the improvement observed after training should be greater for novice than experienced drivers (Groeger, 2001).

Partial support is provided for Hypothesis 1. The results show that although evaluations of distance information can be improved through simulator training, speed perception does not seem to improve in a similar manner. This suggests that drivers have very little absolute knowledge of one of the most basic elements of their driving behaviour i.e. their driving speed, and this does not appear to be amenable to training, at least using the approach adopted here. It would be interesting to conduct further studies including strictly controlled environmental cues to see what effect this would have on drivers' ability to perceive speed.

The null hypothesis cannot be rejected for Hypothesis 2 as very few experience-related differences emerged for either training regime. There was some evidence that novice drivers might have poorer distance evaluation skills than experienced drivers as there was a moderate non-significant trend of novice drivers under-estimating distances by a greater amount than experienced drivers, although there were no differences when producing distances.

Overall, these results provide support for the idea that drivers' evaluation of speed is very poor. It would appear that these skills cannot be improved through simulator-based training, although it is possible that similar training in a real-world context could be successful. Experienced drivers do not appear to have an advantage over novice drivers in terms of understanding either speed or distance behaviour while driving, suggesting that this is not the cause of any experience-related differences in hazard perception ability.

5 Chapter 5: Situation Awareness Training

The second training regime focuses on the higher order concept of situation awareness (SA). SA has been linked on many occasions to hazard perception, with some arguing that they are equivalent concepts (Horswill & McKenna, 2004; McGowan & Banbury, 2004; Underwood et al., 2011). Endsley (1995a) defined situation awareness (SA) as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future” (p. 36).

As discussed in Chapter 1, SA comprises of three stages; perception, comprehension and projection. Perception refers to knowledge of elements in the environment at any given time; comprehension is the understanding of the significance of those elements; and projection is the ability to predict the future actions/states of those elements (Endsley, 1995a). A number of different SA measurement methods have been developed, the most cited of which is the Situation Awareness Global Assessment Technique (SAGAT) (Endsley, 1995b). SAGAT is a method in which a simulation of a system is paused and usually blanked at randomly selected times, and operators are asked probing questions about their knowledge of the system at that moment. The questions should involve all three levels of operator SA requirements, including perception of the data, comprehension of meaning and projection of the near future. According to Endsley (2000), this type of assessment provides an objective measure of SA and allows perceptions to be collected immediately while fresh in the operators minds. Endsley (2000) has found no effects of interruption on participants SA when performances on interrupted and uninterrupted trials were compared. Similarly Snow and Reising (2000) found no negative effects of interruption, but noted that participants attentional behaviour may be altered by the questions asked. McGowan and Banbury (2004) did find a negative effect of interruption on scores in a hazard perception test which required participants to use a computer mouse to click on hazardous events in a driving video. There was an increase in test scores after relevant SA queries, leading the authors to suggest that the lack of an effect of interruption in previous studies may be due to the positive effects of the orienting queries.

SA has received less attention in a road transport context than in other fields such as aviation, the military, and healthcare. This is despite the fact that failures related to poor SA, such as inattention, have been identified as key causal factors in road traffic accidents (Salmon, Stanton, & Young, 2012). Much of the driving research around situation awareness has focused on the effects of driver distraction on awareness of the environment. Kass, Cole, and Stanny (2007) used SAGAT to examine the impact of distraction on situation awareness while driving on a PC-based simulator. Participants in the distraction condition received a call on a hands-free set and were asked a number of questions designed to provide cognitive distractions. Results indicated that there was a significant difference between novice and experienced drivers in the number of SA questions answered correctly, and in their ability to follow a set of driving directions (although it was not clarified what aspect of SA this was measuring). In a study with a stronger design, Ma and Kaber (2005) also used SAGAT to examine the impact of cell phone conversations and adaptive cruise control (ACC) technology on drivers' SA in a medium fidelity driving simulator. During simulation pauses, participants were required to recall car locations and colours or traffic signs they had passed. They were also required to identify any necessary driving behaviours (acceleration, braking, and turning) to improve their accuracy in a car following task. Finally they were asked to predict the times to certain events e.g. time to next turn, or to pass next visible sign. Results indicated that engaging in a cell phone conversation significantly decreased participants comprehension of the situation and ability to project states of the driving environment. The use of ACC improved SA scores across all levels. Correlation analysis found a significant negative linear relationship between total SA score and subjective workload ratings. There were also significant negative linear associations between total SA score and variations in headway distance and following speed. This research provides evidence that SA is impaired under situations of high workload while driving. Therefore, it would seem important that drivers receive adequate training in the aspects of the environment that require the most attention.

In the most widely referenced driving study of SA, Gugerty (1997) used a PC- based driving simulator to focus on the SA knowledge needed for the driving subtask of monitoring the locations of vehicles around them. Gugerty wanted to tap into both explicit (recall) and implicit (performance) knowledge. Participants watched animated scenes lasting from 18 to 35s and were instructed to imagine that their simulated car was on autopilot. At the end of each scene, knowledge of the locations of other vehicles was probed using either recall probes, performance probes, or both. For the recall probes the moving scene disappeared, and participants were asked to indicate the locations of traffic on a birds-eye image of the road, after which they received feedback with the correct final car locations for that scene. In the performance probes, on some trials, an incident would occur that required a driving response: for example, a car would move into the driver's lane ahead of or behind the driver while moving slowly or fast enough that it would collide with the driver. Participants could avoid these hazards by using the keyboard arrow keys to accelerate, decelerate, move to the lane on the left, or move to the lane on the right. Results indicated that the explicit and implicit measures of SA were highly correlated, i.e. better explicit recall of car locations was associated with better performance while controlling the vehicle. The percentage of cars remembered by participants decreased as memory load (i.e. number of cars encountered) increased. There was a positive correlation between both measures of SA and global driving performance, as measured using the percentage of hazards successfully avoided. This study provides an example of the usefulness of multiple methodologies when measuring SA. However, as testing took place in a very de-contextualised environment with unintuitive response requirements, it is not clear how accurate a representation of driving behaviour is provided.

The research outlined in this section provides evidence that the acquisition and maintenance of SA becomes increasingly difficult as the complexity and dynamics of a driving situation increase. Drivers are required to make many decisions across a narrow space of time and these decisions are dependent on an on-going, up-to-date analysis of the environment (Endsley, 1995a). Because the state of the environment is constantly changing, often in complex ways, a major portion of the operator’s job becomes that of obtaining and maintaining good SA (Endsley, 1995a). Although few driving studies have examined the manner in which SA skills are acquired, research suggests that more experienced drivers fixate on hazards earlier than novice drivers (e.g. Underwood et al., 2011), suggesting that SA is something which improves with experience. Therefore, the purpose of this chapter is to develop a regime to improve novice drivers’ perception, comprehension, and projection skills in an attempt to improve their overall hazard perception performance. Performance will be compared to that of experienced drivers, who would presumably have these skills already. Previous research has shown SAGAT to be a valid measure of SA, but there have been some queries as to the negative effects of interruption on drivers' performance. Therefore, in this study SAGAT will be used in conjunction with two performance-based measures designed to evaluate participant projection of future states, thus providing both implicit and explicit measures of SA.

5.1 Study aim and research questions

The purpose of this study is to design and evaluate a situation awareness training regime.

The specific hypotheses being addressed are as follows:

- Hypothesis 1: Higher order driving awareness skills i.e. situation awareness can be improved through simulator-based training.
- Hypothesis 2: Novice drivers performance will be worse than that of experienced drivers prior to training but the improvement observed after training should be greater for novice than experienced drivers (Groeger, 2001).

5.2 Method

5.2.1 Participants

A total of 20 participants volunteered for the study, 10 males and 10 females. The novice drivers had less than two years total driving experience (M=0.35yrs, SD=0.43) with an age range of 19.33 to 27.33 years (M=21.46yrs; SD=2.44). The experienced group had between 5 and 15 years driving experience (M=8.57yrs, SD=2.50) and an age range of 22.04 years to 38.31 years (M=28.15yrs; SD=4.72). The groups differed significantly in terms of experience ($t(18)=-3.98$, $p<0.001$) and age ($t(18)=-10.24$, $p<0.001$).

5.2.2 Apparatus

All of the training took place in UCC's driving simulator. A 30 minute drive was developed in which the number of pedestrians, other traffic, and sign-posts was strictly controlled. The drive was designed so that it automatically paused and cut-to-black after projection events at 10 points during the drive. Projection events were designed to provide objective, performance based, measures of driver's ability to predict future states of the environment based on their own current behaviour, and that of other road users.

Each drive contained four sets of traffic lights, with amber onset occurring when the driver was different distances away (see Table 49). One second after amber onset the screen went blank for one more second before the simulation was paused. This was to ensure that participants made a decision about their behaviour within a second of the traffic light changing colour. This event was designed to encourage participants to think more about how their acceleration and braking decisions were linked to stopping/clearing times.

Table 49: Amber onset distances for traffic light events during Situation Awareness training

Amber Onset Zone	Distance from Participant (metres)
Safe Stopping Zone	90
Dilemma Zone (far)	69
Dilemma Zone (near)	57
Safe Crossing Zone	45

Drivers were randomly divided into either a car emerging or a pedestrian training group. The pedestrian training drive consisted of six pedestrian events, whereby a pedestrian would start to move from either the right or left hand side of the road when the participant was five seconds away. For three of the events, visibility was interrupted by the pedestrian moving behind a vehicle for one second. For the other three events, the pedestrian was fully visible throughout their movement (see Figure 39).

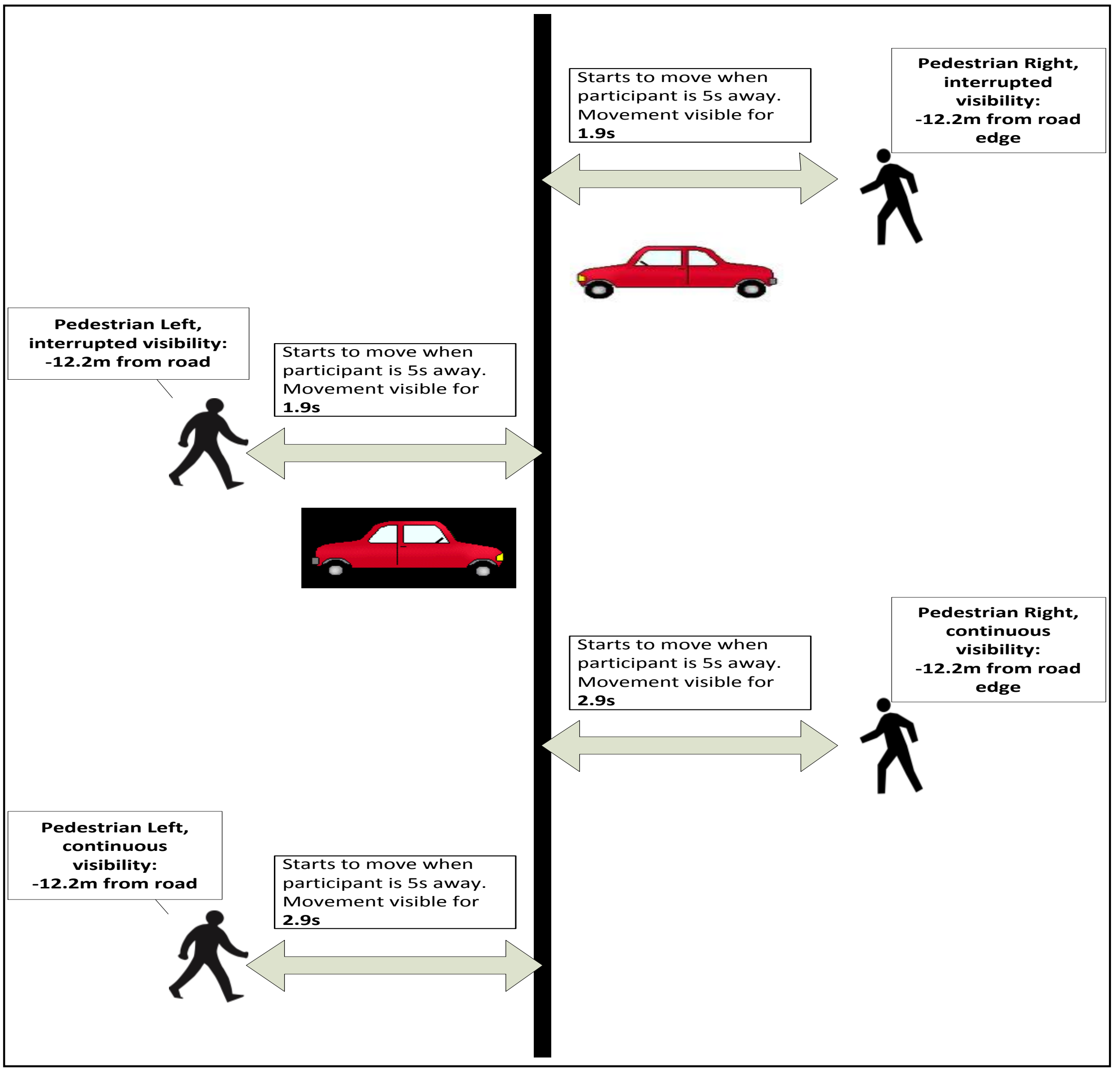


Figure 39: Diagram representing continuous and interrupted visibility pedestrian events in Situation Awareness Training

The car emerging training drive consisted of six events, whereby a car would start to pull out from either the right or left hand side of the road when the participant was either four or six seconds away. Three four second events and three six second events were included in each drive (see Figure 40).

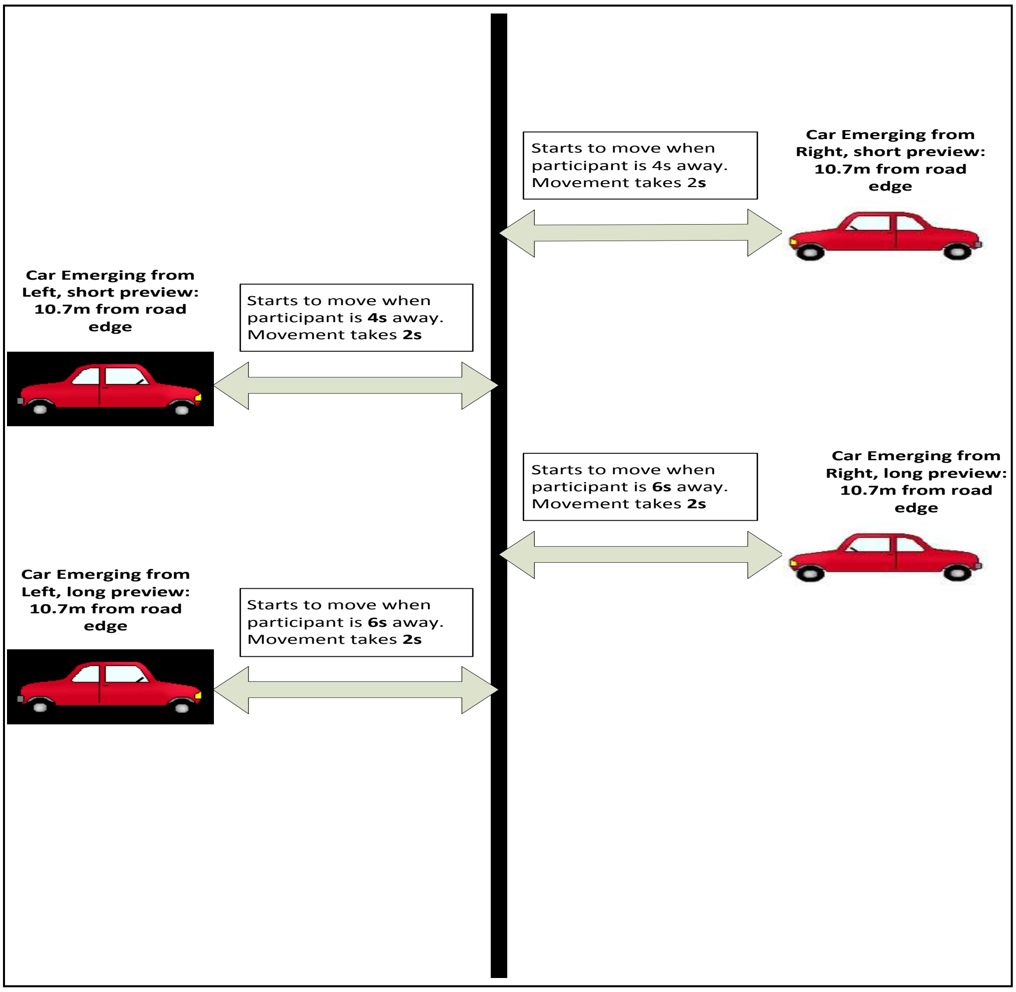


Figure 40: Diagram representing car emerging events in Situation Awareness Training

Both the pedestrian and car emerging events were designed to provide participants with training in the projection of other road users movement patterns. The conditions were separated in order to evaluate when and if transfer of training would occur (see Chapter 6) i.e. participants were put in either the pedestrian condition or the car emerging condition.

A probe recall method was adopted to assess the perception and comprehension aspects of situation awareness. At five points during the drive the simulation was paused, and the screen flashed to black. Participants were asked four questions about things which had happened since the last time the screen had gone blank (the screen went blank after every traffic light and pedestrian/car emerging event). The question topics covered pedestrians encountered, other traffic, signposts, and contents of the rear-view mirror (for full list of questions see Appendix E). Comprehension of the driving situation was assessed by asking participants to judge the elements of the driving environment which they felt were the most hazardous or had the potential to be hazardous at the point at which the screen went blank. These elements were previously determined and included things like cars crossing at an intersection, large vehicles which may have been blocking pedestrians etc.

5.2.3 Design and Procedure

On the first day of training participants filled out informed consent and SSQ forms. They then completed a pre-training hazard perception test (discussed in Chapter 6). After the hazard perception test they were given a 10 minute break while the driving simulator was set up for the next part of the study. The experiment was then explained to them and they were given a 10 minute practice session containing traffic light and car emerging/pedestrian events to get used to the processes involved. During this session they were encouraged to ask any questions they had.

Participants were told that they would encounter two types of events during their drive – traffic lights changing colour and either cars pulling out or pedestrians walking out. For the traffic light events, participants were instructed to make a decision about whether they would stop or go based on how far they were from the junction at the point at which a given traffic light turned amber. They were asked to either brake as much as they thought was necessary to come to a safe stop at the traffic light; accelerate enough to clear the junction safely before the light went red; or, maintain current speed if they thought they could clear the intersection at their current speed. One second after the traffic light turned amber, the screen went blank so that participants could not use their location in relation to the traffic lights to re-adjust their behaviour. They were told to maintain their selected pressure on either the brake or accelerator pedals once the screen went blank. One second later, the simulation was paused and participants were asked whether they had decided to stop or to go, and whether or not they thought they had made the correct decision. In addition, during some of the pauses they were asked a five perception and comprehension questions.

Half of the participants were in the pedestrian condition and half were in the car emerging condition. There were six pedestrian/car emerging events in each drive. In the pedestrian condition, participants were told to listen for a bell, after which they would see a pedestrian begin to move from either the left or the right hand side of the road. The pedestrian came to a stop once it reached the edge of the road, but participants were asked to judge how long it would take the pedestrian to reach the centre of the driver's lane if it had kept moving. They were told to base their decision on both their own, and on the pedestrian's speed, and to sound the horn at the point at which they thought the pedestrian would have reached the centre of the driver's lane. The car emerging condition was very similar. In this condition, when the bell sounded participants were instructed to watch out for a car which would move perpendicular to the road on either the right or left hand side. As in the pedestrian condition, the car stopped moving when it reached the edge of the road and participants were asked to sound the horn at the point at which they judged the rear of the emerging vehicle would reach the centre of their lane if it had kept moving.

After five of the projection events, participants were asked a series of five probes about the driving environment, based on SAGAT (see Section 5.0). Four of the probes related to the perception level of SA, and one probe related to the comprehension level (i.e. participants ability to identify elements of the environment that could be potentially hazardous). In order to minimise practice effects, the order of the questions was changed across sessions, as were the specific questions asked (e.g. asking the number of child pedestrians on one occasion and the number of dogs on another).

Each training session lasted for approximately 30 minutes, at the end of which participants received summary feedback on their performance. The feedback consisted of three graphs providing information on the average accuracy of their brake and accelerator responses at traffic lights, the accuracy of their horn sound times for pedestrians/car emerging events approaching from the right and from the left, and their average response accuracy to each of the five question topics.

Training took place over four days, following the same format each day. The order of drives and questions was counterbalanced across participants and days. After the last training session, participants once again completed the hazard perception test (see Chapter 6).

The dependent variables were as follows:

- Proportion of correctly answered perception questions
- Proportion of correctly answered comprehension questions
- Accuracy of traffic light decisions (Response accuracy is measured as a proportion of the correct pedal change)
- Accuracy of pedestrian/car emerging decisions (response accuracy is measured as a proportion of the correct response time).

The independent variables were as follows:

- Experience Group (between-groups)
- Training Day
- Perception question topic (pedestrians, other vehicles, signposts and mirrors)
- Comprehension question (potential hazards in the environment)
- Traffic light response (acceleration or deceleration, response accuracy is measured as a proportion of the correct pedal change amount)
- Accuracy of pedestrian/car emerging decisions (response accuracy is measures as a proportion of the correct response time).

5.3 Results

A series of analyses of variance were conducted to evaluate participants' changes in perception, comprehension and projection behaviour across training days.

5.3.1 Response Accuracy to Perception Questions

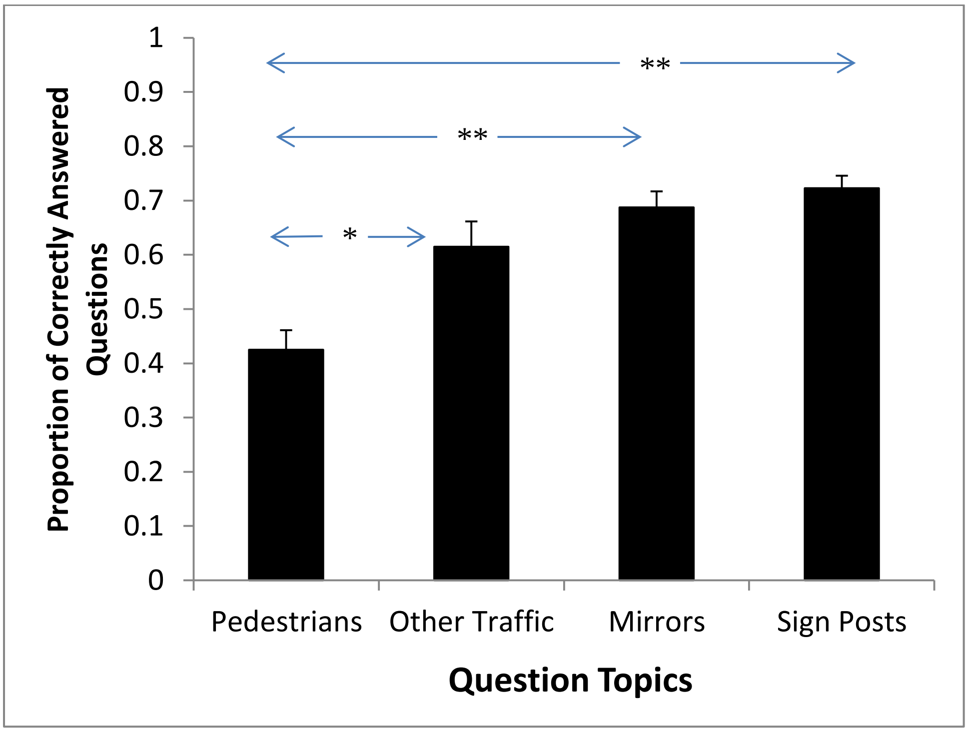
Firstly, in order to assess participants' perception skill, a three-way mixed between-within groups analysis of variance was conducted. Questions were asked at five different time points during the drive. Four questions were asked at each time, with one relating to each of the following: pedestrians, other vehicles, signposts, and rear-view mirrors. The within-groups variables were training day and question topic, and the between groups variable was experience group. The dependent variable was the proportion of correctly answered questions about elements of the environment (see Table 50).

Table 50: Effects of experience group, training day, and question topic on the proportion of perception questions correctly answered

	Df	F	p	η_p^2
Experience Group	1,18	0.23	0.64	0.01
Training Day	1,18	16.96	0.001	0.49
Question Topic	3,16	17.04	<0.001	0.49
Day * Experience	1,18	0.01	0.93	<0.001
Topic * Experience	3,16	0.18	0.91	0.01

Training day had a large, significant effect on the proportion of correctly answered perception questions ($F(1,18)=16.96$, $p<0.001$, $\eta_p^2=0.49$), with participants responding correctly to significantly more questions on the last day of training (M=67.4%, SE=2.2) than on the first day of training (M=55.1%, SE=2.9).

Question topic also had a large, significant effect on the proportion of correctly answered questions ($F(3,16)=17.04$, $p<0.001$, $\eta_p^2=0.49$; see Figure 41).



*p<0.05, **p<0.01

Figure 41: Effect of question topic on the proportion of correctly answered perception questions (mean values, error bars represent standard error)

A Bonferroni comparison of means showed that participants made significantly fewer correct responses to pedestrian questions than to questions about other traffic (MD=0.19, SE=0.06, $p<0.05$); what, if anything, was visible in their rear-view mirror (MD=0.26, SE=0.04, $p<0.001$); or what signposts they had passed (MD=0.30, SE=0.05, $p<0.001$). There were no other significant differences in the accuracy of question responses.

There was no significant difference between experience groups in terms of the proportion of questions answered correctly, with novice drivers answering 60.3% (SE=3.0) and experienced drivers answering 62.3% questions accurately (SE=3.0). There were no significant interaction effects on the proportion of correct responses to perception questions.

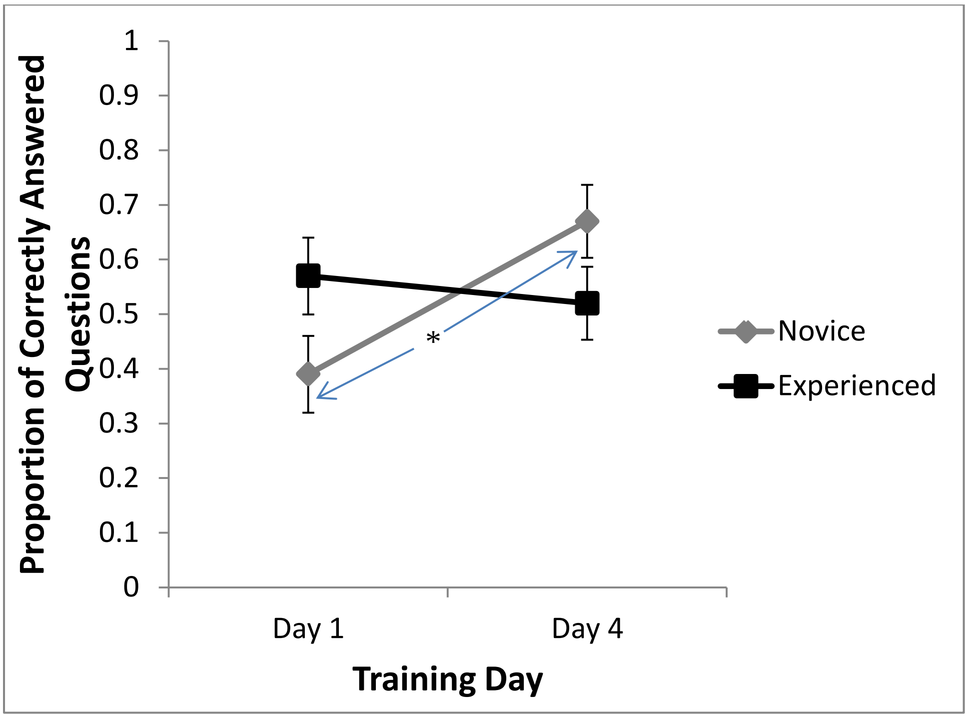
5.3.2 Response Accuracy to Comprehension Questions

In order to evaluate participants understanding of hazardous elements of the driving situations (i.e. comprehension), a two-way mixed between-within groups analysis was conducted to examine the effects of training day (within groups) and experience group (between groups) on the proportion of correctly answered questions (see Table 51).

Table 51: Effect of experience group and training day on proportion of comprehension questions correctly answered

	Df	F	p	η_p^2
Experience Group	1,18	0.05	0.83	0.05
Training Day	1,18	2.87	0.11	0.14
Day * Experience	1,18	5.90	0.03	0.25

Training day did not have a significant effect on response accuracy ($F(1,18)=2.87$, $p=0.11$), although an examination of the means shows that response accuracy improved from 48.0% (SE=5.0) correct on day one of training to 59.5% (SE=4.7) correct on day four. The large effect size of 0.14 suggests that this difference may be meaningful. Experience group also did not significantly affect the proportion of correctly answered comprehension questions ($F(1,18)=0.05$, $p=0.83$). There was, however, a large significant interaction between experience group and training day ($F(1,18)=5.90$, $p<0.05$, $\eta_p^2=0.25$), and this is displayed in Figure 42 below.



*p<0.05

Figure 42: Interaction between experience group and training day on the proportion of correct responses to driving comprehension questions (mean values, error bars represent standard error)

There was no significant difference in the proportion of comprehension questions correctly answered by novice and experienced drivers on either the first or the last day of training. Although the difference approached significance on day one (t(19)=-1.81, p=0.09, |*d*|=0.81; novice M=0.39, SE=0.06; experienced M=0.57, SE=0.08), this effect had completely disappeared by day four (t(19)=1.59, p=0.13, |*d*|=0.71, novice M=0.67, SE=0.07; experienced M=0.52, SE=0.07). Novice drivers performance on comprehension questions improved significantly between the first and last day of training (t(9)=-2.98, p<0.05, |*d*|=1.35). On day one they answered an average of 39.0% (SE=6.4) of questions correctly, and this had improved to 67.0% (SE=6.7) by day four. There was no significant difference in the number of questions experienced drivers answered correctly on the first and last day of training (t(9)=0.51, p=0.62, |*d*|=0.22). These results suggest that the training was effective in bringing novice participants understanding of the hazards in the driving environment up to that of experienced drivers, although both groups still missed hazardous elements of the environment at the end of training.

5.3.3 Projection Tasks

In the following sections, participant's performance on the projection tasks will be evaluated. These tasks were designed to assess and improve level three SA.

5.3.3.1 Response Accuracy to Traffic Light Events

A three-way mixed between-within groups' analysis of variance was conducted to examine the effects of training day, acceleration/deceleration response, and experience group on the accuracy of responses to traffic lights (see Table 52). Participants were deemed to have made an accurate response if they put the correct amount of pressure on the brake to come to a stop just at the traffic light, or if they put the correct amount of pressure on the accelerator to clear the intersection without breaking the speed limit. Response accuracy is measured as a proportion of the correct pedal change amount. Participants in both the pedestrian and car emerging conditions encountered the same traffic light events, and thus the groups were amalgamated for this analysis.

Table 52: Effect of experience group, training day, and type of response on response accuracy to traffic lights

	Df	F	p	η_p^2
Experience Group	1,18	1.55	0.23	0.08
Training Day	1,18	0.25	0.63	0.01
Response Type (Acc/Dec)	1,18	0.07	0.80	0.004
Day * Response Type	1,18	5.26	0.03	0.23
Day * Experience	1,18	1.04	0.32	0.06
Response * Experience	1,18	1.23	0.28	0.06

As Table 52 shows there were no significant main effects of training day ($F(1,18)=0.25$, $p=0.63$), experience group ($F(1,18)=1.55$, $p=0.23$), or response type i.e. acceleration/deceleration ($F(1,18)=0.07$, $p=0.80$). Both novice ($M=0.84$, $SE=0.07$) and experienced drivers ($M=0.96$, $SE=0.07$) tended not to change their speed enough, although both groups accuracy level was quite high.

There was, however, a large significant interaction effect between training day and response type ($F(1,18)=5.26$, $p<0.05$, $\eta_p^2=0.23$) and this is displayed in Figure 43 below.

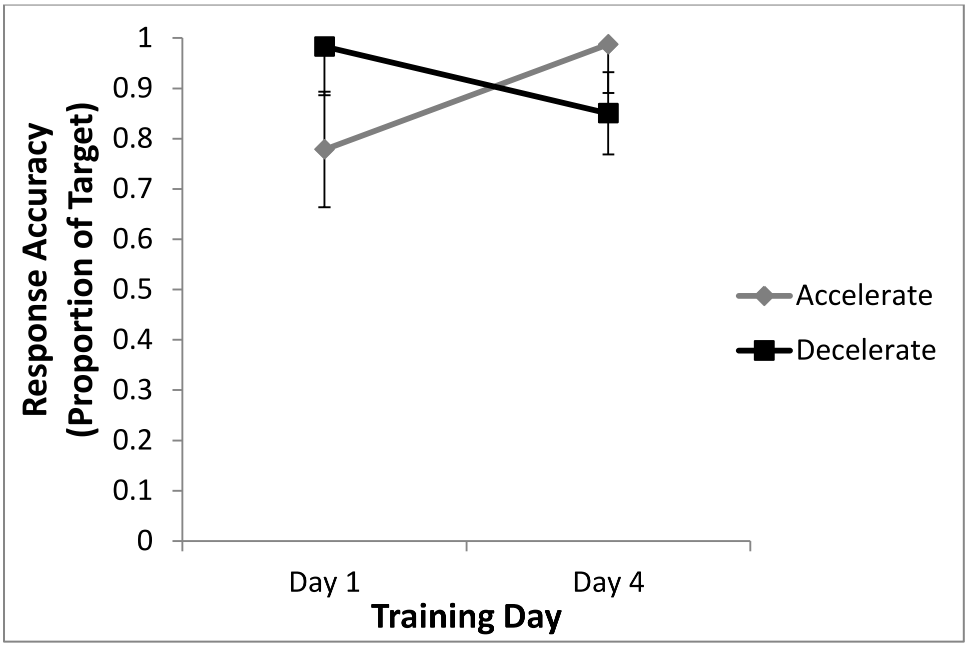


Figure 43: Interaction between training day and response type on the accuracy of traffic light responses (mean values, error bars represent standard error)

Independent samples t-tests showed that there was no significant difference in accuracy of acceleration ($t(19)=-1.75$, $p=0.10$, $|d|=0.45$) or deceleration responses ($t(19)=1.46$, $p=0.16$, $|d|=0.32$) between day one and day four. Participants showed slightly more accuracy in how much they accelerated to clear a set of traffic lights at the end of training (M=0.99, SE=0.09) than at the beginning (M=0.78, SE=0.11), although the small Cohen's *d* value suggests that this was not a meaningful difference. In general participants did not accelerate enough to comfortably clear the intersection, or brake sufficiently at amber onset before the traffic lights went red.

5.3.3.1.1 Summary of Traffic Light Results

Results indicated that participants did not show an overall improvement in the accuracy of their traffic light decisions across training days. Although participants did improve slightly in the accuracy of their acceleration when they decided not to stop at an amber traffic light, they did not show a similar improvement in their rate of braking to come to a comfortable stop at the lights. Participants were actually very close to accurate in their levels of deceleration for traffic lights on the first day of training, suggesting that drivers have quite good SA projection skills when it comes to understanding appropriate behaviour at traffic lights.

5.3.3.2 Pedestrian Events

A four-way mixed between-within groups analysis of variance was conducted to examine the effects of the within groups variables of training day, pedestrian approach direction (left/right), pedestrian visibility (continuous/interrupted), and the between groups variables of experience group on the accuracy of pedestrian responses. Response accuracy was measured as a proportion of correct response time. The results are displayed in Table 53.

Table 53: Effect of experience group, training day, pedestrian direction, and pedestrian visibility on response accuracy to pedestrian events, as a proportion of correct response time

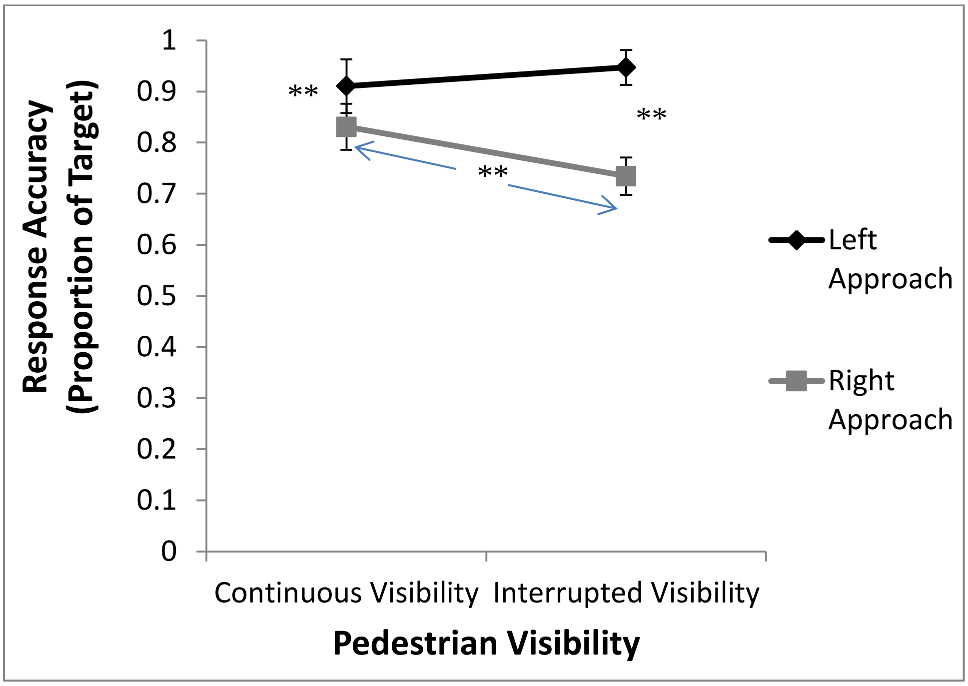
	Df	F	p	η_p^2
Experience Group	1,8	3.59	0.10	0.31
Training Day	1,8	6.39	0.04	0.44
Direction of Approach (Left/Right)	1,8	36.71	<0.001	0.82
Pedestrian Visibility	1,8	2.02	0.19	0.20
Direction * Visibility	1,8	25.77	0.001	0.76
Day * Experience	1,8	0.81	0.40	0.09
Direction * Experience	1,8	0.31	0.60	0.04
Visibility * Experience	1,8	2.40	0.16	0.23

Training day had a large, significant effect on the accuracy of responses to pedestrian events ($F(1,8)=6.39$, $p<0.05$, $\eta_p^2=0.44$). Participants were significantly less accurate in predicting the location of pedestrians on the first day of training (M=0.82, SE=0.04) than on the last day of training (M=0.90, SE=0.05).

Although the effect of experience group did not reach significance ($F(1,8)=3.59$, $p=0.10$), the large effect size ($\eta_p^2=0.31$) suggested an examination of the means would be worthwhile. Unexpectedly, novice drivers (M=0.93, SE=0.06) actually underestimated less than experienced drivers (M=0.78, SE=0.06) in their predictions of pedestrian movement.

The direction from which the pedestrian was approaching also had a large, significant effect on the accuracy of predictions ($F(1,8)=36.71$, $p<0.001$, $\eta_p^2=0.82$). Participants made significantly more accurate responses to pedestrians emerging from the left (M=0.93, SE=0.04) than to those approaching from the right (M=0.78, SE=0.04).

The visibility of pedestrians and the direction from which they approached led to a significant interaction effect on the accuracy of participant's judgements ($F(1,8)=25.77$, $p<0.001$, $\eta_p^2=0.76$). This is displayed in Figure 44.



**p<0.01

Figure 44: Interaction between pedestrian visibility and approach direction on the accuracy of predictions of time to reach road centre (mean values, error bars represent standard error)

As Figure 44 shows, participants were significantly less accurate at judging the movement of both continuous ($t(9)=3.55$, $p<0.01$, $|d|=0.46$) and interrupted visibility pedestrians ($t(9)=7.16$, $p<0.001$, $|d|=1.75$) approaching from the right than from the left. In addition when pedestrians approached from the right, participants were less accurate in their predictions of interrupted visibility pedestrians than continuous visibility pedestrians ($t(9)=4.95$, $p<0.001$, $|d|=0.64$). However, when the pedestrian approached from the left, there was no difference in the accuracy of predictions of continuous and interrupted visibility pedestrians ($t(9)=-1.17$, $p<0.27$, $|d|=0.24$). These results suggest that participants had much more difficulty judging the movement of all pedestrians approaching from the opposite side of the road, particularly those whose visibility was interrupted for a period of time.

5.3.3.2.1 Summary of Pedestrian Results

The results indicate that participant's ability to predict the movements of pedestrians improved significantly between the first and the last day of training, providing evidence for the effectiveness of the training in improving participant's projection skills, at least in terms of understanding pedestrian movement. The analysis of the direction of pedestrian approach and pedestrian visibility shows us that participants had more difficulty in judging the movements of pedestrians who were further away from them. This effect became more pronounced when the visibility of the pedestrian was interrupted for a period of time.

5.3.3.3 Response Accuracy to Car Emerging Events

As with the pedestrian condition, a four-way mixed between-within groups analysis of variance was conducted to examine the within groups variable of training day, car approach direction (left/right), movement time (4/6 seconds away), and the between-groups variable of experience group on the accuracy of car emerging responses (see Table 54). Once again, response accuracy was measured as a proportion of the correct response time.

Table 54: Effect of experience group, training day, car approach direction, and movement time on response accuracy to car emerging events, as a proportion of correct response time

	Df	F	p	η_p^2
Experience Group	1,8	0.01	0.92	0.001
Training Day	1,8	38.45	<0.001	0.83
Direction of Approach	1,8	7.24	0.03	0.48
Movement Time	1,8	1.84	0.21	0.19
Day * Experience	1,8	0.02	0.88	0.003
Direction * Experience	1,8	0.01	0.92	0.001
Movement * Experience	1,8	0.57	0.47	0.07

Training day had a large, significant effect on the accuracy of predictions about when approaching cars would reach the centre of the road ($F(1,8)=38.45$, $p<0.001$, $\eta_p^2=0.83$). Participants underestimated how long this would take on both days, but were significantly more accurate on day four of training (M=0.64, SE=0.05) than on day one (M=0.44, SE=0.03).

The direction of approach also had a significant effect on the accuracy of responses ($F(1,8)=7.24$, $p<0.05$, $\eta_p^2=0.48$). Participants made more accurate judgements for cars emerging from the left ($M=0.59$, $SE=0.04$) than from the right ($M=0.49$, $SE=0.04$), although once again they were inclined to underestimate how long both manoeuvres would take.

Experience group did not have a significant effect on projection accuracy ($F(1,8)=0.01$, $p=0.92$), with novice and experienced drivers under-estimating by a similar proportion ($M=0.54$, $SE=0.05$). There were also no significant interaction effects on the prediction of car emerging events.

5.3.3.3.1 Summary of Car Emerging Results

After four days of training, participants showed significant improvement in their ability to project the future movement of cars pulling out. However, they still dramatically underestimated how long this process would take. This shows that both novice and experienced drivers have great difficulty in interpreting the movement of speed of cars moving perpendicularly across their path. Perhaps this could have been further improved with more training, as an analysis of means across all four days shows a steady improvement in accuracy each day (see Table 55).

Table 55: Mean accuracy of car emerging projection times across all four training days

Training Day	Mean Accuracy (Proportion of Target)	SE
Day 1	0.44	0.03
Day 2	0.50	0.02
Day 3	0.56	0.04
Day 4	0.64	0.05

5.4 Discussion

The purpose of this study was to investigate the development of the higher order skill of situation awareness. This training regime was more successful than the basic perception and control regime (see Chapter 4), as all three levels of SA showed some improvements after training.

Participant's perception of the elements of their environment improved significantly between the first and the last day of training. One aspect of perception that seemed particularly difficult for participants was knowledge about pedestrians encountered. One potential reason for this was that they had difficulty distinguishing between child and adult pedestrians. Another potential cause relates to mental workload. Many studies have found that SA deteriorates with increases in mental workload (Gugerty, 1997; Kass et al., 2007; Ma & Kaber, 2005). It is possible that since the questions about pedestrians were the only ones which required participants to count, this may have led to increased mental load, and thus extra difficulty in remembering the numbers of a particular type of pedestrian encountered.

Although there was no main effect of training day on the response accuracy of drivers to questions regarding their comprehension of the dangerous elements of a situation, a significant interaction effect shows that novice driver's comprehension scores improved significantly after training, reaching a level of understanding that was similar to experienced drivers. This shows that the training was successful in improving novice drivers level 2 SA, bringing it up to the same level as their more experienced (and presumably safer) counterparts.

The measure of projection used in this study, aimed to provide an objective, performance-based understanding of how drivers predict their own movement and the movement of other drivers. This was different from the SAGAT measures which have been used in previous driving studies (Kass et al., 2007; Ma & Kaber, 2005), and provides a more ecologically valid measure than the computer based performance measures of Gugerty (1997). The three measures of participant projection skills showed mixed effectiveness. Training in the projection of driver's own brake/accelerator movement at traffic lights did not lead to much improvement in performance, although participants understanding of the acceleration needed to safely clear a traffic intersection did improve slightly. As participants had very good accuracy scores on their braking behaviour on the first day of training, it may be that this is an element of SA projection which does not require training. The effect of training on the projection of pedestrian movement was more positive, with participants showing significant improvements in their judgement of how quickly a moving pedestrian would reach the centre of their lane. Participants seemed to have the most difficulty in understanding the movement of pedestrians approaching from the opposite side of the road, particularly when those pedestrians disappeared behind another vehicle for a period of time. Generally, pedestrian movement only becomes problematic when pedestrians draw close to a vehicle, and therefore it is possible that drivers have no previous experience with judging the movement of pedestrians that are far away. It may also be that pedestrians approaching from the opposite side of the road are in the periphery of the driver's visual field, thus making their movements more difficult to interpret. Finally, it would appear that novice drivers actually had a better understanding of pedestrian movements than experienced drivers. This finding did not quite reach significance and therefore should be treated with caution. However, it provides an interesting understanding of the trend of the training results. It was expected that training would benefit novice drivers more than experienced drivers, but that experienced drivers level of performance would still be superior to that of novice drivers. It may be that driver training which addresses the projection of the positions of other road users is most beneficial early in a driver's career, before ideas about motion become too entrenched. Future research, with larger sample sizes would help to explore this finding further. Although training led to an accuracy improvement in the judgement of the movement of other vehicles, participants still underestimated how quickly emerging cars would reach the centre of their lane by approximately 34% after training. This shows that drivers have great difficulty in interpreting the movement and speed of cars moving perpendicularly across their path. Perhaps this could have been further improved with more training, as there was a general pattern of increasing accuracy every day. The fact that drivers are under-estimating rather than over-estimating the movement times of other vehicles is good from a safety point of view as they will have more time than they expect to take any avoidance action that may be necessary. It is possible that this is linked to the finding of the first study that participants tend to under-estimate distance and over-estimate speed, which would lead to faster estimations of movement times. The current data does not allow a statistical analysis of this finding, but it provides an interesting example of how basic perceptions of speed and distance can link to projections about elements of the driving environment.

5.4.1 Summary and Conclusions

The specific hypotheses being addressed are as follows:

- Hypothesis 1: Higher order driving awareness skills i.e. situation awareness can be improved through simulator-based training.
- Hypothesis 2: Novice drivers performance will be worse than that of experienced drivers prior to training but the improvement observed after training should be greater for novice than experienced drivers (Groeger, 2001).

The results provide support for Hypothesis 1. It would appear that the higher order concept of SA can be trained using a driving simulator, as elements of all three levels of SA improved after training.

However, Hypothesis 2 is not supported. Very few experience-related differences emerged for either training regime. It would appear that novice drivers have poorer level 2 situation awareness skills than experienced drivers, as they responded correctly to fewer of the comprehension questions prior to training than experienced drivers did. However, there were no differences between the two groups in terms of their perception or projection ability.

6 Chapter 6: Transfer of Training and Replication of Hazard Handling Test

6.1 Transfer of Learning

Psychologists have long sought to answer concerns about how new responses are generated when individuals are confronted by novel stimulus situations or task demands. This is particularly relevant in driving research because safe driving depends on the transfer of what is learned during training, or past experience, to a wider range of circumstances than could ever be encountered during training (Groeger & Banks, 2007). Although current driver training systems have high face validity to programme providers and parents (Lonero, 2008), there is little evidence that they lead to transfer benefits after training, with one in five UK drivers having a road traffic accident within the first year of passing their driving test (Wells et al., 2008). The DeKalb County project, conducted in the US in the 1970's and 80's found no association between driver education (consisting of classroom education, simulator training and on-road training), and reliable differences in road traffic accident involvement. An evaluation of other studies conducted the UK, Sweden, New Zealand and Quebec provides no more reassurance, with little evidence of any safety benefit from different training regimes (Brown, Groeger, & Biehl, 1987; Mayhew, Simpson, Williams, & Ferguson, 1998). The situation has not improved much since the 1990's with Groeger and Banks (2007) claiming to have found little evidence for any safety benefits from formal driver training. However, the authors did find some evidence that graduated driver licensing regimes in which driving in certain conditions (e.g. night-time) is restricted for a period of time after licensure, can lead to safety benefits by providing novice drivers with time to practice manoeuvres more often prior to encountering more dangerous situations, as well as raising the age at which they do so.

Mayhew et al. (1998) recommend that any driver education/training programme should be integrated into a graduated licensing system, and the programme should be evidence-based, focusing on the psychomotor, perceptual and cognitive deficiencies (e.g. hazard perception, speeding) that are associated with novice drivers' high collision rates. With this in mind, the aim of this chapter is to examine levels of transfer from the two training programmes outlined in Chapters 4 and 5 to the hazard handling test developed in Chapters 2 and 3.

Transfer is defined as the "use of knowledge or skill acquired in one situation in the performance of a new, novel task" (Pennington, Nicolich, & Rahm, 1995, p. 176). Blume, Ford, Baldwin, and Huang (2010) claim that transfer consists of two major dimensions: (a) *generalization* or "the extent to which the knowledge and skill acquired in a learning setting are applied to different settings, people, and/or situations from those trained", and (b) *maintenance* or "the extent to which changes that result from a learning experience persist over time" (p.1067-1068).

6.1.1 When does transfer of learning occur?

Although transfer of learning has been analysed for over a century, the literature remains characterised by inconsistent measurement of transfer and significant variability of findings (Blume et al., 2010). There is little agreement in the scientific community about the nature of transfer, the extent to which it occurs, and the nature of its underlying mechanisms (Barnett & Ceci, 2002). Many studies have failed to find any evidence for the occurrence of learning transfer, and in certain cases it has been found that participants actually have worse performance on transfer tasks than they would have if they had not been exposed to the initial training task in the first place. This is known as negative transfer (Barnett & Ceci, 2002)

As early as 1906, Thorndike developed his theory of identical elements in which he claimed that in order for transfer to occur the original learning and transfer situations must share identical elements, typically interpreted as shared features of physical environments or common stimulus elements (Lobato, 2006). Anderson's (1982) ACT theory also supports the identical elements view, because according to that theory learning depends on the development of productions which improve as a function of the number of times a particular manoeuvre is practised/situation is encountered, and are use-specific to a particular goal (see Section 3.1.1 for detailed description of ACT model). However, although there is substantial evidence which supports this position, more recent studies which have focused on abstraction, namely a deeper-level understanding of concepts, have found evidence for the ability to transfer principles, albeit only in certain situations (see Barnett & Ceci, 2002; Groeger, 2000). A number of studies suggest that verbal mediation, rather than production similarity, mediates transfer (Groeger, 2000). For example, using an analysis of transfer of learning of programming skills, Pennington et al. (1995) found that transfer was declarative not procedural in nature. Participants made detailed codings of declarative knowledge elaborations after each problem solving and feedback trial, and used these to generate effective problem solutions.

Nokes (2009) has provided further evidence of the use of declarative knowledge in the transfer of learning. He developed three types of training for the analysis of letter combinations (e.g. generate the next six letters of the sequence CDDEFF_). The first of these was analogical training involving the use of exemplars. The second type of training was tactics training, involving the use of knowledge compilation skills i.e. providing information that was designed to facilitate the formation of production rules from declarative information. Finally, the third type of training was called constraints training, and was designed to tap into the concept of constraint violation, a generate-evaluate-revise transfer cycle in which the learner was provided with potential strategies for addressing problems. Three different transfer tests were used to analyse the most effective training strategies for transfer. The first test used a similar problem to one of the exemplars provided in the analogy training. The second test had a number of different solutions depending on what tactic was used e.g. if exemplars were used one solution was most likely, but if knowledge compilation was used, another solution was more likely. The third transfer test had neither surface nor deep structure similarity to the exemplar problems and there was no pattern-finding tactic that could be directly applied to the pattern. Results showed that the exemplar participants (analogical transfer training) solved the first transfer problem more quickly than the other groups, suggesting that they transferred both declarative and procedural knowledge, promoting the idea of identical elements. The tactics (knowledge compilation) and constraints groups had long solution times similar to the no-training group, suggesting that they had to compile or articulate their prior knowledge in order to solve the problem, although all three training groups had higher accuracy scores than the no-training group. On the second transfer problem the training groups had similar accuracy scores to the no-training group. All three groups had long solution times similar to the no-training group, suggesting that they had to engage in significant amounts of cognitive processing to generate the correct solution. However, in a second study in which participants were trained in all three techniques and were asked to verbalise their thought processes while solving transfer problems, it was found that many participants used knowledge compilation tactics even when direct exemplars of transfer problems had been provided. In addition, the provision of all three training strategies led to a significant difference in the accuracy performance of participants in the second transfer problem. For the most complex transfer problem in this study, trained participants showed more accuracy than untrained participants, and trained participants made more statements of constraints and error checking for this problem than the more similar transfer problems. The results showed that when participants were provided with training in all three transfer strategies (analogical, knowledge compilation, and constraint violation), they shifted between multiple mechanisms of problem-solving depending on their prior knowledge and specific characteristics of the transfer task. The results also show that the less that one's prior exemplar knowledge matches the current situation, the more likely one is to shift to knowledge compilation of applicable declarative knowledge. Constraint violation will only be triggered when one has no accessible exemplars and when tactical knowledge does not apply. This study provides evidence that the transfer of learning is often linked to verbal processing of learned materials prior to the production of procedural rules. However, the use of this verbal mediation proved to be costly in terms of the time taken to generate problem solutions and thus, may not be possible in situations where there are time-restraints. It is unlikely that drivers will have sufficient time after appraising a threat in the environment to go through all of the response options in a declarative manner, and thus the requirements for transfer of learning in driving contexts are more than just correct response selection.

Section 1.5.1 in Chapter 1 provided information on a number of studies looking at transfer of learning in a driving context. Commentary training (whereby participants are asked to either develop or listen to verbal commentaries of hazards presented in a driving video) has been found to improve drivers response times to hazards presented in computer and simulator based hazard perception tests (Crundall et al., 2010; McKenna et al., 2006; Wallis & Horswill, 2007; see Chapter 1). Anticipation training, which involves the generation of verbal predictions of future events in traffic situations, has also been linked to improved hazard perception performance (Fisher et al., 2006; McKenna & Crick, 1997; Pradhan et al., 2009) These studies provide some further evidence for the benefits of verbal mediation strategies in the transfer of driving skills. However, there is no evidence that transfer of learning can occur in the absence of such verbal mediation (Groeger & Banks, 2007).

6.1.2 Taxonomies of Transfer

Nokes (2009) argues that people have multiple transfer mechanisms and that it is likely that these mechanisms are adapted in response to the knowledge they possess, how it is encoded, and the relationship between the training and transfer problems. However, there has been little attempt to empirically investigate when and where transfer of learning is most likely to take place.

Barnett and Ceci (2002) developed a taxonomy of transfer to tackle this issue, in which they claim that studies should distinguish between the content and the context of transfer. Content refers to what is transferred from the learning to the testing situation, and context refers to when and where it is transferred from. They use a number of content and context domains to provide a deeper understanding of near transfer ("transfer to a more similar context") and far transfer, or ("transfer to a dissimilar context") (p.615). Their taxonomy consists of nine distinct categories which they have used to reclassify the transfer literature in order to demonstrate where and when transfer of learning can occur. They found a number of studies which resulted in transfer to a far domain with near physical and temporal contexts (e.g. Gick & Holyoak, 1980), but none which resulted in far transfer on the other domains, providing clearly defined boundaries for where exactly any "far" transfer occurs, something which is missing from most other studies.

Groeger and Banks (2007) have adapted Barnett and Ceci's (2002) model for use in a driving context, separating out the content and the circumstances of the learning environments (see Table 56 and Table 57). In the driving context, knowledge domain refers to the degree of relationship between the driving manoeuvres already practiced and the transfer manoeuvre required; physical context refers to the vehicle being driven and the external circumstances, temporal context refers to the time since learning and performance of the transfer task, functional context refers to the purpose and constraints operating at the time of learning and transfer; and social context refers to those who may witness performance and their degree of participation in it.

Groeger and Banks (2007) also add a dimension of state-task situational demand, which encompasses the level of demand imposed upon the driver by the transfer task, their own state and preoccupations and the distractions and demands arising from passengers, telephones etc.

This framework provides a methodology for the evaluation of where and when transfer of learning could be expected to take place within a driving context, thus enabling a more strictly controlled assessment of near and far transfer.

Table 56: Groeger and Banks (2007) Framework for evaluating the content of anticipated transfer of learning

	Content of Anticipated Transfer		
	Specific ←	→	**General**
Learned Skill	Procedure (or action)	Alternative representation of task requirements	Apply abstract principle across task
Performance Change	Speed/Accuracy	Smoothness/Efficiency	Safety
Memory Demands	Execute Only	Recognize and Implement	Recognize, select and execute

Table 57: Groeger and Banks (2007) Framework for evaluating the circumstances of transfer of learning

	Circumstances of Anticipated Transfer				
	Near ←			→	**Far**
Knowledge Domain	Same Manoeuvre	Similar, but easier manoeuvre	Less similar, but easier manoeuvre	Less similar, less easy manoeuvre	Different, harder manoeuvre
Physical Context	Same car, same location	Different car, same location	Different car, similar location	Different car, less similar location	Different car, different location
Temporal Context	Same session	Next Day	Weeks later	Months later	Years later
Functional Context	Formal lesson	Lesson vs. assessment drive	Lesson vs. demanding drive	Lesson vs. leisure drive	Lesson vs. driving tired late at night
Social Context	Driving with tutor	Driving under supervision	Driving alone	Driving with peer	Driving with noisy peers
Modality	Driving in lesson	Driving lesson vs. driving in test	Test vs. post-test driving	Post-test classroom vs. post-test driving	Classroom pre-driving vs. post-test driving
State/Task/Situational Demand	Lone driver, rested, light traffic, easy known situation	Lone driver, rested, heavy traffic, easy unknown situation	Lone driver, tired, heavy traffic, unknown situation	Distracted driver, new, easy situation	Tired driver, distracted, new difficult situation

6.1.3 Aims of the current study

In Chapters 4 and 5, the results of two driver training regimes were outlined. The first training programme focused on the development of perceptual and vehicular control skills through intense training in judgements of speed and distance. The training regime succeeded in improving participants' ability to produce distances accurately, although there was no effect on the ability to estimate distances. There was also no change in participants' ability to evaluate their travelling speed as a result of training. The second training regime focused on the development of higher order situation awareness (SA) skills. The focus was on improving drivers' perception, comprehension and projection skill while driving. Results indicated that improvements occurred in aspects of all three dimensions of SA, with both novice and experienced drivers scores on perception and comprehension questions improving after training, along with their ability to predict the movement of other road users, specifically pedestrians and cars emerging perpendicularly to the road.

The current chapter will evaluate the level of transfer of learning arising from both training regimes to a hazard handling test conducted on the last day of training. This evaluation will be based on Groeger and Banks (2007) taxonomy for learning transfer.

The Speed and Distance training was defined as being "far" from the testing situation on all three dimensions of content. In order for any transfer of learning to occur in the hazard handling test, the training required participants to apply the abstract general principles of speed and distance evaluation learned through training to different scenarios in the testing environment e.g. stopping time for traffic lights. It was general rather than specific on the dimension of performance change, with the testing scenario requiring drivers to drive more safely based on the abstract awareness of speed and distance gained through training. General knowledge was also required on the memory demands dimension as there were no hints provided that the testing scenario was in any way linked to the training contexts. In terms of circumstances, the hazard handling test required near transfer on temporal context, functional context, social context, modality, and situational demand. However, far transfer was required on the physical context domain as training took place in a featureless environment, whereas the testing scenario was feature-rich. In addition far transfer was required on the knowledge domain as the hazard handling test required participants to use abstract knowledge of their speed and distance behaviour to choose more appropriate speeds and stopping distances in the hazard handling test.

The Situation Awareness training was closer in content to the hazard handling test than the Speed and Distance training. It required specific knowledge on the dimension of learned skill, but a more general performance change that was different from what was taught in training. Participants were presented with traffic lights, and pedestrians or car emerging events which were similar to, although not exactly the same as the events presented in the hazard handling test. Similar to the speed and distance training, the dimension of memory demands once again required participants to recognise, select, and implement actions based on a memory of knowledge gained through training, although no hints of this overlap were explicitly provided. The hazard handling test required near transfer on the temporal context, functional context, social context, modality, and situational demand dimensions of the circumstances domain. However, far transfer was required on the knowledge domain as the manoeuvres taught in training were different from those required in the transfer context, although the physical context was similar.

The specific hypotheses being addressed in this study were as follows:

- Hypothesis 1: Training in basic vehicle control and perception elements i.e. speed and distance, will lead to transfer of learning resulting in improved performance in dimensions of a hazard handling test.
- Hypothesis 2: Training in higher order driving skills i.e. situation awareness will lead to transfer of learning resulting in improved performance in dimensions of a hazard handling test.
- Hypothesis 3: Hazard handling performance after training will be different for drivers in the speed and distance group than in the situation awareness group, as the two groups differ in terms of how ‘near’ or ‘far’ they are from the testing context in terms of Groeger and Bank’s (2007) taxonomy.

- Hypothesis 4: Members of the control group will not show any change in hazard handling behaviour between their first and second times taking the test.

A final aim of this study was to further examine if the results presented in Chapter 2 and 3 of this thesis could be replicated i.e. did the same differences emerge between novice and experienced drivers in terms of their response times to hazardous events and was performance across the two hazard handling tests significantly correlated? This allows an evaluation of the reliability of the hazard handling test as a measure which can distinguish between novice and experienced drivers.

6.2 Method

6.2.1 Participants

A total of 60 participants took part in the study (30 males and 30 females), 20 in each training group. Details of the two training groups (speed and distance, and situation awareness) are outlined in Chapters 4 and 5 respectively. A third group acted as controls: these participants did not receive any training, but also completed the hazard handling test on two occasions, separated by a minimum of four and a maximum of seven days (M=5.22 days, SD=1.26). The control group consisted of 10 novice and 10 experienced drivers. The novice drivers had a mean of 0.37 years driving experience (SD=0.27), and an age range of 19.24 to 20.36 years (M=19.84yrs; SD=0.35). The experienced group had an average of 8.15 years driving experience (SD=3.17) and an age range of 22.02 years to 32.56 years (M=26.71yrs; SD=3.59). The groups differed significantly in terms of both age ($t(18)=-6.03$, $p<0.001$), and experience ($t(18)=-7.28$, $p<0.001$). Participants received €10 per laboratory visit upon completion of this study.

One-way analysis of variance showed that there were no significant differences between the novice drivers in the speed and distance group, the situation awareness group, and the control group in terms of either driving experience ($F(2,27)=0.81$, $p=0.46$, $\eta_p^2=0.05$) or age ($F(2,27)=2.34$, $p=0.12$, $\eta_p^2=0.14$). There was also no difference between the experienced drivers in the three groups in terms of driving experience ($F(2,27)=0.17$, $p=0.84$, $\eta_p^2=0.01$) or age ($F(2,27)=0.32$, $p=0.73$, $\eta_p^2=0.02$).

6.2.2 Apparatus

Both the pre- and post-training hazard handling tests took place in UCC's driving simulator. The hazard handling test was similar to that used in Chapter 3. However, in order to shorten the duration of the drive a number of changes were made. The 25kph zone was eliminated as it took over 6 minutes to drive, and feedback from participants was that it did not feel realistic to them. In addition, because no differences had emerged in previous studies between bends with continuous and interrupted visibility, the number of bends included in each speed zone was reduced from six to three (i.e. twelve bends in total), leading to a total of forty hazardous events. As a result of the exclusion of bends, the number of control events was reduced to twenty-eight in this drive with a reduction of straight stretches of road from twenty to twelve. Finally, the curvature of the bends was standardised across speed-zones to make it easier to make comparisons. Once again there were three levels of bend curvature (small=69.91m radius, medium=116.51m radius, and large=348.6m radius). All bends had full continuous visibility, with no impairments to vision throughout the curve. The rest of the hazards were the same as version two of the hazard handling test outlined in Chapter 3.

6.2.3 Design and Procedure

On the first day of training participants filled out informed consent and SSQ forms. They then completed a 10-minute practice drive to become accustomed to the simulator, after which the hazard handling test was explained to them. They were given full control of the vehicle and asked to drive as they normally would. The word "hazard" was not mentioned at any stage. The hazard handling test took approximately 20 minutes to drive, after which participants completed one of the training regimes outlined in Chapter 4 and 5, which lasted between four and seven days (M=5.41 days, SD=1.46). After completion of the last training session, participants once again drove the hazard handling route, with the same instructions as the pre-training drive. After completion of the second hazard handling drive, participants were fully de-briefed as to the purpose and aims of the study.

A control group also completed the two hazard handling tests with a break of between four and seven days between testing sessions. There were ten participants assigned to the speed and distance control group and ten assigned to the situation awareness control group. Participants in the speed and distance control group completed one speed drive and one distance drive without feedback after the first hazard handling test; and one speed drive and one distance drive without feedback prior to the hazard handling test on their second visit to the laboratory. Participants in the situation awareness control group completed one situation awareness drive with no feedback after the hazard handling test on the first day, and one situation awareness drive prior to the hazard handling test on their second day. For the purposes of the analyses described in this chapter, these two groups were amalgamated.

6.3 Results

In the first part of this section, the test-retest performance of the control group will be evaluated. This will be followed by a comparison of the performance of the two training groups in the hazard handling tests prior to and after training to determine whether or not the training led to any improvements in hazard handling performance.

6.3.1 Test-Retest Performance of Control Group

The control group of participants performed the hazard handling test on two occasions with no training in between. In order to evaluate the test-retest reliability of the test, a correlational analysis was performed between this groups' response rate and response time scores in the first and second implementations of the hazard handling test. The results of this analysis are displayed in Table 58.

Table 58: Pearson's Correlations between response rates (RR) and response times (RT) of the control group on their first and second Hazard Handling test

	N	M	SD	T1: RR	T2: RR	T1: RT	T2:RT
Test 1: Mean Response Rate(RR)	20	0.94	0.04	1			
Test 2: Mean Response Rate(RR)	20	0.92	0.04	0.26	1		
Test 1: Mean Response Time(RT)	20	0.57	0.06	-0.17	-0.18	1	
Test 2: Mean Response Time(RT)	20	0.58	0.09	0.21	-0.01	0.06	1

Unexpectedly, there were no significant correlations between response rate and response times scores in the first and second implementations of the hazard handling test. This suggests that participants' reactions to hazardous events changed between carrying out the first and second presentations of the test.

However, this analysis focuses on individual's performances at Time One and Time Two, and does not take account of whether or not responses to stimuli showed a similar pattern at both time-points.

In order to establish whether or not the stimuli were measuring the same thing in both implementations of the hazard handling test, response rates and response times to each individual hazard were averaged across participants, and the correlations between performance at Time One and Time Two were evaluated. The results of this analysis are presented in Table 59 below.

Table 59: Pearson's Correlations between average response rates (RR) and response times (RT) of the control group to individual hazards at Time 1 and Time 2

	N	M	SD	T1: RR	T2: RR	T1: RT	T2:RT
Test 1: Mean Response Rate(RR)	40	0.92	0.13	1			
Test 2: Mean Response Rate(RR)	40	0.91	0.16	0.90**	1		
Test 1: Mean Response Time(RT)	40	0.55	0.43	-0.21	-0.33**	1	
Test 2: Mean Response Time(RT)	40	0.56	0.46	-0.28	-0.34**	0.90**	1

**p<0.01

Taking account of the effects of individual stimuli, there is a large positive correlation between response rates at Time One and Time Two (Pearson's *r*=0.90, p<0.01). There is also a large, positive correlation between response times to stimuli at Time One and Time Two (Pearson's *r*=0.90, p<0.01). This suggests that hazard stimuli are providing the same measurements at both time points. There was a medium, negative relationship between response rates at Time Two and both response time at Time One (Pearson's *r*=-0.33, p<0.01) and response time at Time Two (Pearson's *r*=0.34, p<0.01). This indicates that the more stimuli that were responded to, the faster the responses were made. However, this relationship failed to emerge for response rates at Time One, suggesting it may be a practice effect.

These results suggest that although individual participants' reactions to hazardous events did not remain stable across the two presentations of the hazard handling test, average response patterns to individual stimuli did not change. This provides support for the assumption that the hazard handling test is a reliable measure.

6.3.1.1.1 Control Group: Comparing Experience Groups

In order to investigate whether or not the response rates and times of novice and experienced drivers changed significantly between the first and the second sitting of the hazard handling test, a three way mixed between-within groups analysis of covariance was conducted, controlling for any age effects (see Table 60). The between-group variable was experience group and the within-groups variables were hazard category (i.e. car emerging, merging traffic, pedestrian, traffic light, bend) and test implementation (first/second).

Table 60: Effect of experience, hazard category and test time on Control Group participant's response rates to hazards, with age as a covariate

	Df	F	p	η_p^2
Experience Group	1,17	1.11	0.31	0.06
Age in years	1,17	1.61	0.22	0.09
Hazard Category	4,14	2.14	0.09	0.11
Test Time (first/second)	1,17	0.18	0.68	0.01
Hazard * Experience	4,14	0.76	0.56	0.04
Test Time * Experience	1,17	0.09	0.77	0.01
Test Time * Hazard	4,14	0.76	0.55	0.04
Hazard * Test Time * Experience	4,14	0.86	0.49	0.05

Experience group did not have a significant effect on response rates to hazards across the two tests ($F(1,17)=1.11$, $p=0.31$), with novice ($M=0.95$, $SE=0.02$) and experienced drivers ($M=0.92$, $SE=0.02$) making a similar number of responses. Test implementation number (i.e. first/second test) also had no effect on the number of responses made ($F(1,17)=0.18$, $p=0.68$) with participants responding to an average of 93.8% hazards ($SE=0.90$) in the first test and an average of 92.4% hazards ($SE=1.00$) in the second.

The effect of hazard category approached significance ($F(4,14)=2.14$, $p=0.09$) and the medium effect size ($\eta_p^2=0.11$) prompted an examination of the mean response rates. These mean response times are displayed in Figure 45.

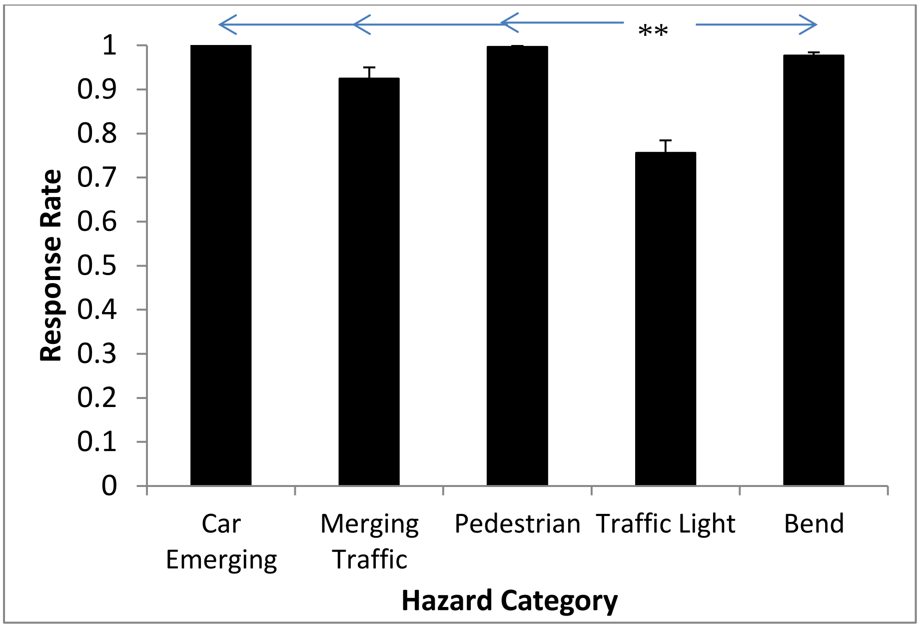


Figure 45: Control Group response rates to hazard categories across in their first and second Hazard Handling test (mean values, error bars represent standard error)

As with previous versions of the hazard handling test (see Chapters 2 and 3), participants responded to fewer traffic light events than to any other hazard. Response rates were over 90% for all other hazards.

A three-way mixed between-within groups analysis of covariance was also conducted to examine experience effects on response time, controlling for any age effects (see Table 61). The between-group variable was experience group and the within-groups variables were hazard category (i.e. car emerging, merging traffic, pedestrian, traffic light, bend) and test implementation (first/second).

Table 61: Effect of experience, hazard category and test time on Control Group's response times to hazards, covarying out age effects

	Df	F	p	η_p^2
Experience Group	1,17	0.01	0.92	0.001
Age in years	1,17	0.12	0.74	0.01
Hazard Category	4,14	0.89	0.47	0.05
Test Time (first/second)	1,17	0.18	0.67	0.01
Hazard * Experience	4,14	1.17	0.33	0.06
Test Time * Experience	1,17	0.08	0.79	0.004
Test Order * Hazard	4,14	1.74	0.15	0.09
Hazard * Test Time * Experience	4,14	0.21	0.93	0.01

Unlike previous versions of the hazard handling test (see Chapter 2 and 3), experience group did not have a significant effect on response times to hazards across the two tests (F(1,11)=1.11, p=0.31), with novice (M=576ms, SE=26) and experienced drivers (M=572ms, SE=26) taking a similar length of time to respond to hazards. Participants also took a similar length of time to respond to hazards in their first (M=572ms, SE=14) and second (M=576ms, SE=20) presentations of the hazard handling test (F(1,17)=0.18, p=0.67).

The results of the analyses of covariance provide reassurance that the same results emerge from repeated sittings of the hazard handling test. There were no significant differences in either response rates or response times to hazards between the first and second implementations of the test.

6.3.1.1.2 Control Group: Calculating Change Scores

In order to provide final reassurance that participant's responses were not changing significantly between their first and second time taking the hazard handling test, change scores were calculated for each individual hazard category. This was achieved by subtracting the score on the first hazard handling test from the score on the second test. This provides a control for some of the variability in participant response scores, which may explain the lack of significant correlations obtained.

One-sample t-tests were then conducted comparing change scores to zero to determine whether or not any change was significant. The results for both response rate and response time are presented in Table 62.

Table 62: Comparing Control Group change scores to zero – response rate and response time

	M	SD	T	p	Cohen's *d*
			Response Rate		
Car Emerging	<0.001	<0.001	[a]	[a]	[a]
Merging Traffic	-0.05	0.21	-1.07	0.30	0.34
Pedestrian	0.01	0.03	1.00	0.33	0.47
Traffic Light	-0.05	0.15	-1.35	0.19	0.47
Bend	0.02	0.05	1.75	0.10	0.57
All Hazards	-0.01	0.05	-1.21	0.24	0.28
			Response Time		
Car Emerging	0.02	0.21	0.48	0.64	0.13
Merging Traffic	-0.002	0.26	-0.02	0.98	0.01
Pedestrian	-0.002	0.43	-0.02	0.99	0.01
Traffic Light	-0.004	0.41	-0.05	0.96	0.01
Bend	0.004	0.05	0.36	0.73	0.11
All Hazards	0.004	0.10	0.17	0.87	0.06

[a] *t scores could not be computed because the standard deviation was zero.*

Negative *t* scores indicate that participants had longer response times or made more responses on their first time taking the test than on their second time. Positive *t* scores indicate that they had longer response times or made more responses on their second time taking the test. As Table 62 shows none of the change scores for either response rate or response time was significantly different from zero. This indicates that there were no significant changes in responses to any of the hazards between the first and second sitting of the hazard handling test, thus showing that individual participants responded in the same manner to hazards across both versions of the test, at least in terms of speed of response and number of responses made. However, it should be noted that the change score for response rates to bends approached significance ($t(19)=1.75$, $p=0.10$) and the medium effect size (Cohen's *d*=0.57) suggests that this may be a meaningful difference. The positive t value indicates that participants responded to more bends in the second presentation of the hazard handling test than in the first.

6.3.2 Control Variables

In their guidelines for the development of hazard perception tests, Wetton et al. (2011) advocate that tests should be able to identify and classify inappropriate responses, thereby facilitating the detection of people over-responding or trying to cheat the test. In addition, previous versions of the test had elicited very high response rates to hazards and there was some concern regarding the response criterion. In Chapter 3, responses to hazard and control variables were compared and it was shown that participants made significantly fewer changes in behaviour around control variables than around hazards. This section will check that the same difference emerged for participants in the training and transfer study. The control variables were designed to initially look the same as the hazard variables, but they did not move at any stage. Behaviour was measured for the same length of time around the control variable as for the corresponding hazard event (see Section 3.2.2.1 in Chapter 3 for full description).

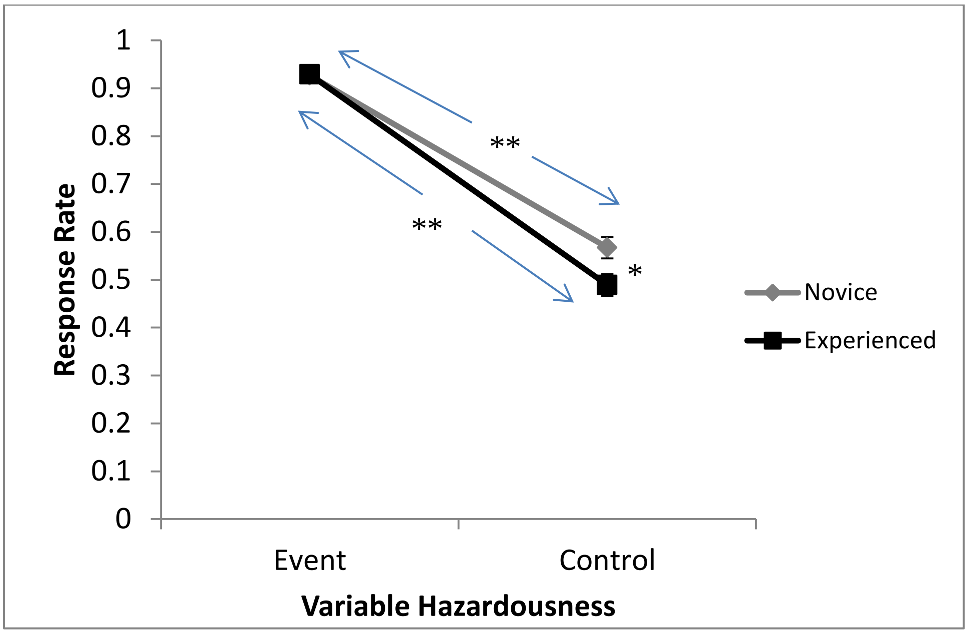
The results of a three-way mixed between-within groups analysis of covariance comparing participant response rates to control and hazard events, controlling for age effects, is presented in Table 63. The between groups variable is experience group, and the within groups variables are variable type (hazard/control) and test implementation (first/second test).

Table 63: Comparing response rates to hazard and control variables in the first and second hazard handling tests

	Df	F	p	η_p^2
Experience Group	1,57	6.82	0.01	0.11
Age in years	1,57	1.05	0.31	0.02
Hazardousness (Hazard/Control)	1,57	61.67	<0.001	0.52
Test Time (first/second)	1,57	1.15	0.29	0.02
Hazardousness * Experience	1,57	9.17	0.004	0.14
Test Time * Experience	1,57	0.77	0.39	0.01
Test Time * Hazardousness	1,57	<0.001	0.99	<0.001
Test Time * Hazardousness * Experience	1,57	0.07	0.80	0.001

Variable hazardousness had a large, significant effect on response rate ($F(1,57)=61.67$, $p<0.01$, $\eta_p^2=0.52$), with participants responding to significantly fewer control events ($M=0.53$, $SE=0.01$) than hazard events ($M=0.93$, $SE=0.004$).

Experience had a medium, significant effect on response rates, separate to any age effects ($F(1,57)=6.82$, $p<0.01$, $\eta_p^2=0.11$). Novice drivers (M=0.75, SE=0.01) responded to more events in total than experienced drivers (M=0.71, SE=0.01). However, the significant interaction between variable hazardousness (hazard/control) and experience group ($F(1,57)=9.17$, $p<0.01$, $\eta_p^2=0.14$) suggests that this is a result of novice drivers responding to more control events than experienced drivers (see Figure 46).



*p<0.05, **p<0.01

Figure 46: Interaction between experience group and variable hazardousness on response rates in Hazard Handling test (mean values, error bars represent standard error)

An independent samples t-test showed that there was no significant difference between the experience groups in the number of responses made to hazardous events across the two tests ($t(38)=-0.59$, $p=0.56$, $|d|=0.18$). There was, however, a significant difference between the number of responses made by novice and experienced drivers to control events ($t(38)=2.54$, $p<0.05$, $|d|=0.81$), with novice drivers (M=0.57, SE=0.02) making significantly more responses to control variables than experienced drivers (M=0.49, SE=0.02). This shows that experienced drivers have better ability to discriminate between hazardous and non-hazardous events than novice drivers. Response rates to control events were significantly lower than response rates to hazardous events for both the novice ($t(19)=24.78$, $p<0.001$, $|d|=5.79$) and experienced groups ($t(19)=18.11$, $p<0.001$, $|d|=5.72$).

A three-way mixed between-within groups analysis of covariance was also conducted to compare participant response times to control and hazard events, controlling for age effects. The results of this analysis are presented in Table 64. The between groups variable is experience group, and the within groups variables are variable type (hazard/control) and test implementation (first/second test).

Table 64: Comparing response times to hazard and control variables in the first and second hazard handling tests

	Df	F	p	η_p^2
Experience Group	1,57	3.45	0.07	0.06
Age in years	1,57	3.48	0.07	0.06
Hazardousness (Hazard/Control)	1,57	1.72	0.19	0.03
Test Time (first/second)	1,57	0.38	0.54	0.01
Hazardousness * Experience	1,57	0.96	0.33	0.02
Test Time * Experience	1,57	0.21	0.65	0.004
Test Time * Hazardousness	1,57	0.21	0.65	0.004
Test Time * Hazardousness * Experience	1,57	0.65	0.43	0.01

There was no significant difference in response times to hazardous (M=562ms, SE=10) and control (M=1003ms, SE=42) events ($F(1,57)=1.72$, $p=0.19$). The effect of experience group on response time approached significance ($F(1,57)=3.45$, $p=0.07$) and the medium effect size ($\eta_p^2=0.06$) suggests that this may be a meaningful difference. Novice drivers (M=829ms, SE=33) took longer to respond to variables than experienced drivers (M=737ms, SE=33).

Overall, the analyses presented in this section show that participants in this study changed their behaviour around significantly fewer control variables than hazard variables, thus providing support for the stringency of the response criterion of a change in steering or pedal behaviour of 2SD. Experienced drivers appeared to show better discrimination between hazardous and control events than novice drivers.

6.3.3 Evaluation of Training Transfer

The previous sections have provided information on the reliability of the hazard handling test, showing that similar results emerge from multiple implementations of the test when nothing occurs to change drivers' behaviour between implementations.

If training was successful in changing drivers' behaviour in relation to hazards in the environment, it would be expected that their hazard handling behaviour would change after training. In the following sections the performance of the two training groups prior to and after training will be discussed to establish whether or not any improvements in hazard handling occurred.

6.3.3.1 Response Rate to Hazards

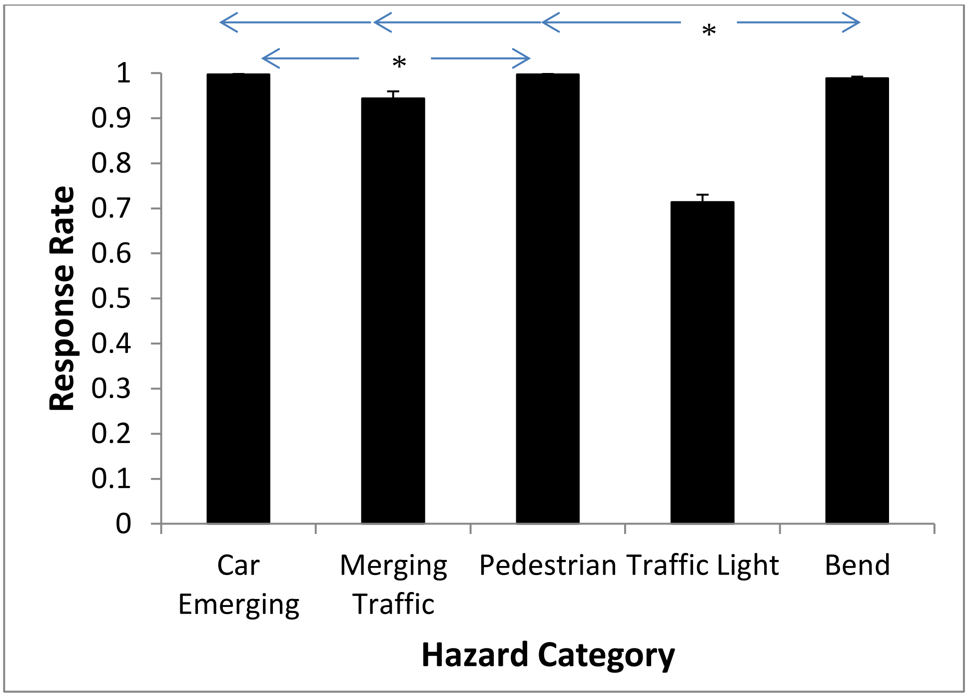
Firstly, participants' response rates to hazardous events prior to and after training were examined. The results of a four-way between-within groups' analysis of covariance, controlling for the effects of age are reported in Table 65. The between groups variables are experience group (novice/experienced) and training group (speed and distance/situation awareness). The within groups variables are hazard category (car emerging, merging traffic, pedestrian, traffic light and bends) and test implementation number (pre/post training).

Table 65: Effect of experience, training group, hazard category and test time on response rate to hazards, with age as a covariate

	Df	F	p	η_p^2
Experience Group	1,35	0.03	0.87	0.001
Age in years	1,35	1.01	0.32	0.03
Training Group (S&D/SA)	1,35	0.15	0.70	0.004
Hazard Category	4,32	13.99	<0.001	0.29
Test Time (Pre/Post Training)	1,35	4.01	0.05	0.10
Hazard * Experience	4,32	0.73	0.57	0.02
Hazard * Training Group	4,32	0.37	0.83	0.01
Test Time * Experience	1,35	4.90	0.03	0.12
Test Time * Training Group	1,35	0.12	0.73	0.003
Test Time * Hazard	4,32	1.37	0.25	0.04
Hazard * Experience * Group	4,32	0.22	0.93	0.01
Test Time * Experience * Group	1,35	0.93	0.34	0.03
Hazard * Test Time * Group	4,32	0.49	0.74	0.01

There was a medium, significant effect of test implementation (pre/post training) on the response rate to hazardous events ($F(1,35)=4.01$, $p<0.05$, $\eta_p^2=0.10$). However an evaluation of the mean response rates shows that participants actually responded to the same proportion of hazards prior to and after training ($M=0.93$, $SE=0.01$). The significant interaction between experience group and test implementation ($F(1,35)=4.90$, $p<0.05$, $\eta_p^2=0.12$) allows further exploration of this relationship (see Figure 48).

Hazard category also has a significant main effect on response rate ($F(4,32)=13.99$, $p<0.001$, $\eta_p^2=0.29$), which is displayed in Figure 47. The response rates to the various different hazards were similar to those obtained in the previous implementations of the hazard handling test (see Chapter 2). The only difference was that participants had lower response rates to merging traffic events than car emerging (MD=0.05, $p<0.05$) or pedestrian events (MD=0.05, $p<0.05$) across the two implementations of this version of the hazard handling test.



*p<0.05

Figure 47: Effect of hazard category on response rates of training groups to hazardous events (mean values, error bars represent standard error)

Finally, although there was no significant main effect of experience group on response rate to hazards ($F(1,35)=0.03$, $p=0.87$), there was a significant interaction between test implementation (pre/post training) and experience on response rate to hazards ($F(1,35)=4.90$, $p<0.05$, $\eta_p^2=0.12$). This is displayed in Figure 48.

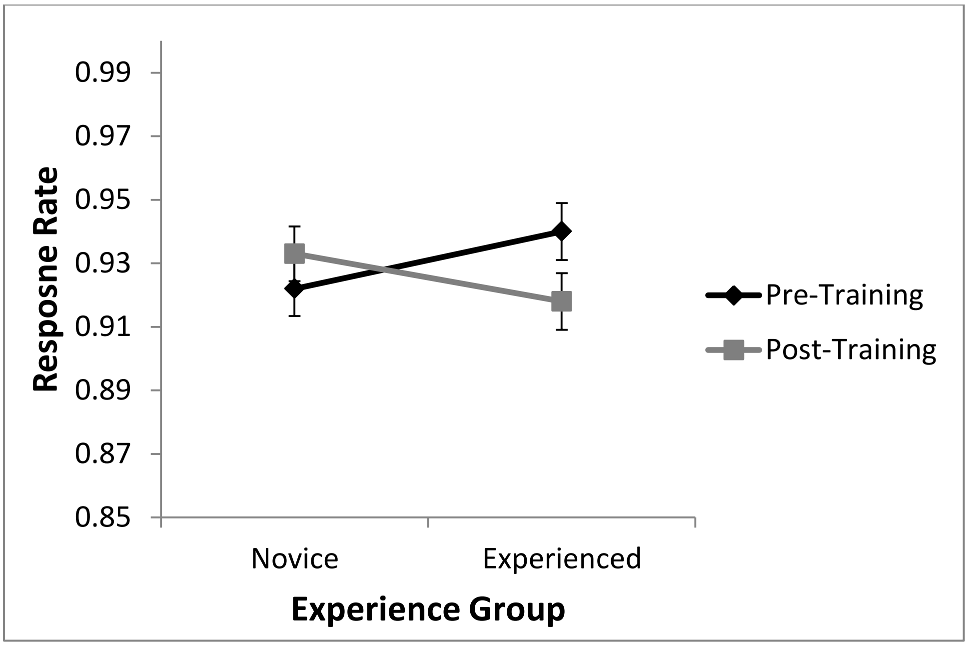


Figure 48: Interaction between experience group and hazard handling time-point on training group's response rates to hazardous events (mean values, error bars represent standard error)

There was no significant differences in the numbers of hazards novice drivers responded to prior to and after training ($t(19)=-0.70$, $p=0.49$, $|d|=0.14$), nor was there any significant difference in the number of hazards experienced drivers responded to across the two tests ($t(19)=1.51$, $p=0.15$, $|d|=0.49$). There were no significant differences in the number of hazards novice and experienced drivers responded in the pre-training ($t(38)=-1.50$, $p=0.14$, $|d|=0.47$) or post-training tests ($t(38)=0.48$, $p=0.64$, $|d|=0.15$).

6.3.3.2 Response Time to Hazards

In order to evaluate whether or not training led to a change in response times to hazardous events, a four way between-within groups analysis of covariance was conducted, with age as the covariate (see Table 66). The between-groups variables were experience group and training group (speed and distance/situation awareness). The within groups variables were hazard test implementation (pre/post training), and hazard category (car emerging, merging traffic, pedestrian, traffic light, bend).

Table 66: Effects of experience, training group, hazard category and test time on response rate to hazards, with age as a covariate

	Df	F	p	η_p^2
Experience Group	1,35	4.49	0.04	0.11
Age in years	1,35	3.91	0.06	0.10
Training Group (S&D/SA)	1,35	1.26	0.27	0.04
Hazard Category	4,32	8.64	<0.001	0.20
Test Time (Pre/Post Training)	1,35	<0.001	0.99	<0.001
Hazard * Experience	4,32	0.79	0.53	0.02
Hazard * Training Group	4,32	0.81	0.52	0.02
Test Time * Experience	1,35	0.18	0.67	0.01
Test Time * Training Group	1,35	4.50	0.04	0.11
Test Time * Hazard Interaction	4,32	4.19	0.003	0.11
Hazard * Experience * Group	4,32	0.44	0.78	0.01
Test Time * Experience * Group	1,35	<0.001	0.99	<0.001
Hazard * Test Time * Group	4,32	1.41	0.24	0.04

There was a medium, significant effect of experience group on response time to hazardous events across the two time points ($F(1,53)=4.49$, $p<0.05$, $\eta_p^2=0.11$), with experienced drivers (M=524ms, SE=21) responding significantly more quickly to hazards than novice drivers (M=589ms, SE=21), which existed independently of any age effects ($F(1,35)=3.91$, $p=0.06$, $\eta_p^2=0.10$).

There was no significant main effect of training group on response time to hazardous events ($F(1,35)=1.26$, $p=0.27$), nor was there any effect of test implementation i.e. pre or post training, ($F(1,35)<0.01$, $p=0.99$). There was however a medium significant interaction between test implementation and training group ($F(1,35)=4.50$, $p<0.05$, $\eta_p^2=0.11$). This is displayed in Figure 49.

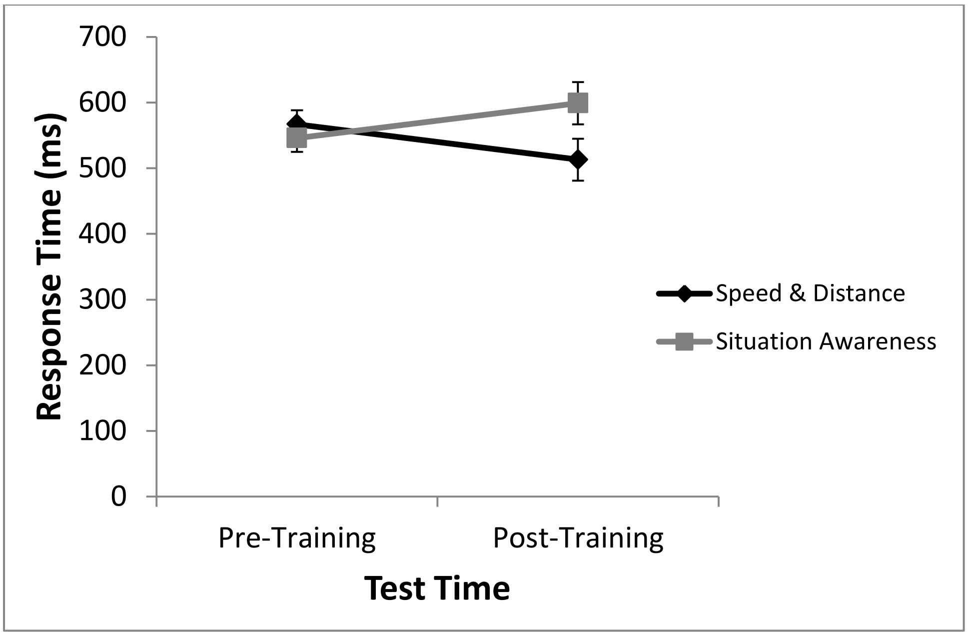
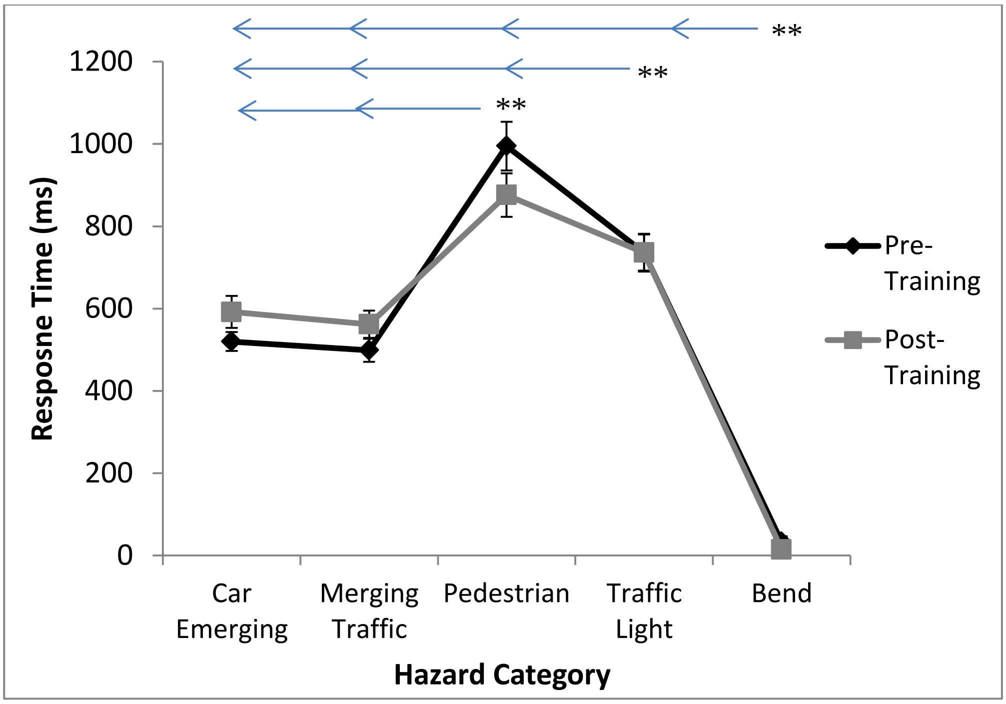


Figure 49: Interaction between training group and pre/post training test on response time to hazards (mean values, error bars represent standard error)

Paired samples t-tests showed that there was no significant change in the response times of the speed and distance training group from pre-training to post-training tests ($t(19)=1.61$, $p=0.13$, $|d|=0.46$), nor was there any significant change for the situation awareness group ($t(19)=-1.55$, $p=0.14$, $|d|=0.43$). Independent samples t-tests show that there was no significant differences between the response times of the two groups in the pre-training test ($t(38)=0.98$, $p=0.33$, $|d|=0.31$). However, the difference between the groups in the post-training test approached significance ($t(38)=-1.73$, $p=0.09$, $|d|=0.55$) and a medium Cohen's *d* effect of 0.55 suggests that this may be a meaningful difference. An examination of the graph shows that the change in response time for the speed and distance group is in the opposite direction to that of the situation awareness group. The effect may not be the result of any significant change in behaviour by either group, but just due to the fact that both groups had a small change in opposite directions.

Hazard category (i.e. car emerging, merging traffic, pedestrian, traffic light, or bend) had a large, significant effect on response time ($F(4,32)=8.64$, $p<0.001$, $\eta_p^2=0.20$). In addition, there was a significant interaction between hazard category and test implementation ($F(4,32)=4.19$, $p<0.01$, $\eta_p^2=0.11$). This is displayed in Figure 50.



**p<0.01

Figure 50: Interaction between hazard type and pre/post training test on response times to hazards (mean values, error bars represent standard error)

As Figure 50 shows, there were no significant differences in response times across hazards between the pre- and post-training tests, although the difference in response time to pedestrian events (t(39)=1.68, p=0.10, |*d*|=0.34) in the pre- and post-training tests approached significance, with participants responding more quickly to pedestrian events in the post-training hazard handling test (M=924.4ms, SE=43.18) than in the pre-training test (M=1004.5ms, SE=42.76). Once again, the pattern of response times to the various hazards was quite similar to the previous implementations of the hazard handling test (see Chapters 2 and 3), with participants demonstrating the fastest response times to bends, and the slowest response times to pedestrian events.

Although there was a small difference in response times to hazards before and after training, there was no difference between the responses of the two training groups across test implementations and hazard categories, as the three way interaction between training group, hazard category, and test implementation failed to reach significance (F(4,32)=1.41, p=0.24).

The results in this section provide initial evidence that transfer of learning from the training to the hazard handling contexts did not occur. There were no significant group changes in behaviour from the pre-training to the post-training tests. The results of this version of the hazard handling test seem to provide further evidence that the test can discriminate between novice and experienced drivers, as once again experienced drivers showed faster overall response times than novices.

6.3.3.3 Change Scores

In order to provide greater clarification of the results discussed in Sections 6.3.3.1 and 6.3.3.2, changes scores for each of the training groups were calculated. This was achieved by subtracting the response rate and response time scores in the pre-training hazard handling test from the same scores in the post-training hazard handling test. These scores were then compared to zero using one-sample t-tests. If any change in behaviour had occurred after training it would be expected that the change score would be significantly different from zero. By comparing individuals' behaviour at the first presentation of the hazard handling test to their own behaviour in the second test, this analysis provides some control for individual variability in scores.

The results of the one-sample t-tests comparing response rate and response time change scores for the Speed and Distance training group are presented in Table 67.

Table 67: Comparing Speed & Distance Group change scores to zero – response rate and response time

	M	SD	T	p	Cohen's *d*
			Response Rate		
Car Emerging	<0.001	<0.001	[a]	[a]	[a]
Merging Traffic	-0.04	0.15	-1.14	0.27	0.38
Pedestrian	<0.001	<0.001	[a]	[a]	[a]
Traffic Light	0.01	0.14	0.45	0.66	0.14
Bend	-0.004	0.05	-0.37	0.72	0.12
All Hazards	-0.01	0.04	-0.57	0.56	0.18
			Response Time		
Car Emerging	0.03	0.29	0.47	0.65	0.15
Merging Traffic	0.04	0.25	0.64	0.53	0.23
Pedestrian	-0.24	0.47	**-2.22**	0.04	0.72
Traffic Light	-0.08	0.34	-1.07	0.30	0.33
Bend	-0.02	0.17	-0.56	0.58	0.17
All Hazards	-0.05	0.15	-1.61	0.13	0.47

[a] *t could not be computed because the standard deviation was zero.*

Negative *t* scores indicate that participants had longer response times or made more responses on their first time taking the test than on their second time. Positive *t* scores indicate that they had longer response times or made more responses on their second time taking the test. The only change score which was significantly different from zero was for response time to pedestrian events. The negative *t* value indicates that participants response times to pedestrian hazards were smaller in the post-training test than in the pre-training test ($t(19)=-2.22$, $p<0.05$), indicating faster responses. The Cohen's *d* value of 0.72 indicates that this was a medium effect.

The results of the one-sample t-tests comparing response rate and response time change scores for the Situation Awareness training group are presented in Table 68.

Table 68: Comparing Situation Awareness Group change scores to zero – response rate and response time

	M	SD	T	p	Cohen's *d*
			Response Rate		
Car Emerging	-0.01	0.06	-1.00	0.33	0.24
Merging Traffic	-0.06	0.18	-1.56	0.14	0.47
Pedestrian	0.01	0.04	1.45	0.16	0.35
Traffic Light	0.05	0.16	1.26	0.23	0.44
Bend	-0.01	0.04	-1.00	0.33	0.35
All Hazards	-0.01	0.05	-0.46	0.65	0.28
			Response Time		
Car Emerging	0.12	0.29	1.79	0.09	0.59
Merging Traffic	0.09	0.34	1.20	0.25	0.37
Pedestrian	-0.001	0.40	-0.05	0.96	0.01
Traffic Light	0.08	0.36	1.02	0.32	0.31
Bend	-0.02	0.03	**-2.18**	0.04	0.94
All Hazards	0.05	0.15	1.55	0.14	0.47

The only change score which differed significantly from zero for the Situation Awareness training group was response time to bends. The negative *t* value indicates that participants responded more quickly to bends in the post-training test than in the pre-training test, and that the change in scores was significant ($t(19)=-2.18$, $p<0.05$). A Cohen's *d* figure of 0.94 indicates that this was a large effect. The change in car emerging response time score approached significance and was a medium sized effect, with a positive *t* value indicating that participants actually took longer to respond to these events in the post training condition ($t(19)=1.79$, $p=0.09$, $|d|=0.59$).

As a number of the change scores emerged as being different from zero, it was decided to explore these further. Firstly, the results suggest that the response time scores of participants in the Speed and Distance group changed in relation to pedestrian events. Therefore, a two-way between-groups analysis of covariance was conducted, comparing the performance of novice and experienced drivers in the Speed and Distance, Situation Awareness, and control groups, controlling for baseline pedestrian response times (i.e. response times to pedestrian events in the first hazard test). The results of this analysis are presented in Table 69.

Table 69: Comparing the three transfer groups' response time change scores in relation to pedestrians, controlling for baseline scores

	Df	F	p	η_p^2
Baseline Pedestrian Response Time	1,53	40.20	<0.001	0.43
Experience Group	1,53	0.05	0.82	0.001
Transfer Group (S&D/SA/Control)	1,53	2.86	0.07	0.10

The effect of transfer group (i.e. Speed & Distance/Situation Awareness/Control) approached significance ($F(1,53)=2.86$, $p=0.07$) with a medium effect size suggesting the effect merited investigation ($\eta_p^2=0.10$). An analysis of means showed that the change score of the Speed and Distance group failed to differ significantly from the change score of the Situation Awareness group (MD=0.19, SE=0.10, p=0.23) but the difference with the Control Group approached significance (MD=0.24, SE=0.10, p=0.08).

Response time change scores of participants in the Situation Awareness group were significantly different to zero in relation to bends. Therefore, a two way between-groups analysis of covariance was conducted on bend change scores, comparing the performance of novice and experienced drivers in the Speed and Distance, Situation Awareness, and control groups, controlling for baseline response times to bends (i.e. response times to pedestrian events in the first hazard test). The results of this analysis are presented in Table 70.

Table 70: Comparing the three transfer groups' response time change scores in relation to bends, controlling for baseline scores

	Df	F	p	η_p^2
Baseline Bend Response Time	1,53	327.77	<0.001	0.86
Experience Group	1,53	0.24	0.63	0.004
Transfer Group (S&D/SA/Control)	1,53	3.12	0.05	0.11

There was a significant effect of transfer group (Speed and Distance/Situation Awareness/Control) on response time changes scores for bends ($F(1,53)=3.12$, $p<0.05$). The response times of the Situation Awareness group were significantly different from those of the Speed and Distance group (MD=0.03, SE=0.01, $p<0.05$) but were not significantly different from those of the Control group (MD=0.02, SE=0.01, $p=0.51$). There was also no significant difference between the Speed and Distance and Control groups (MD=0.01, SE=0.01, $p=0.81$). This suggests that any change in response time to bends was the result of a practice effect rather than training.

Finally, the response time change scores in relation to car emerging events for participants in the Situation Awareness group had a difference from zero approaching significance ($p=0.09$), with a medium Cohen's *d* effect size ($|d|=0.59$) suggesting that this was a meaningful difference. Therefore, a two-way between-groups analysis of covariance was conducted, comparing the performance of novice and experienced drivers in the Speed and Distance, Situation Awareness, and control groups, controlling for baseline car emerging response times (i.e. response times to car emerging events in the first hazard test). The results of this analysis are presented in Table 71.

Table 71: Comparing the three transfer groups' response time change scores in relation to car emerging events, controlling for baseline scores

	Df	F	p	η_p^2
Baseline Car Emerging Response Time	1,53	22.97	<0.001	0.30
Experience Group	1,53	0.46	0.50	0.01
Transfer Group (S&D/SA/Control)	1,53	0.63	0.54	0.02

The results of this analysis of covariance show that there were no significant differences between the change scores of the three groups in relation to car emerging events, when initial response time scores were taken into account ($F(1,53)=0.63$, $p=0.54$). Therefore, the training was not successful in changing participants' responses towards car emerging events to a degree that differed from the control group.

6.4 Discussion

The purpose of this study was twofold. The first aim was to replicate the results obtained in Chapter 2 and 3, and to provide more evidence on the reliability of the hazard handling test.

The second aim was to evaluate if and when transfer of learning would occur from two different driver training regimes to performance in a hazard handling test. Previous research has found limited evidence for transfer of learning when there is no over-lap between the content of the training and testing situations (Groeger & Banks, 2007; Lobato, 2006; Thorndike, 1906), although there is some evidence that verbal mediation can aid in the transfer of knowledge (Groeger, 2000; Nokes, 2009; Pennington et al., 1995).

6.4.1 Replication of Hazard Handling Results

The control group of participants completed the hazard handling test on two separate occasions, with no training in between. Thus, it was expected that if the hazard handling test provided a reliable measure, the same pattern of results should emerge in both implementations of the test. Unexpectedly, no significant correlation emerged between either overall response times or overall response rates to hazards at Time One and Time Two. However, an examination of the relationship between responses to individual hazard stimuli at Time One and Time Two showed that positive correlations emerged for both response rate and response time. Thus, although individual participant's response patterns may have altered between the two test implementations, the stimuli appeared to be providing the same measurements at Time One and Time Two.

The results of the correlational analyses raise some concern that participants were not responding in the same manner to hazardous events at the first and second presentation. However, the results of the various analyses of covariance provide some initial reassurance. The pattern of results emerging for both response rates and response times to the various hazards was quite similar to the previous implementation of the hazard handling test (see Chapters 2 and 3). In addition there were no significant effects of test implementation number (i.e. first or second presentation of the test) on either response rates or response times to hazards.

It is possible that variations in individuals' response patterns to hazards led to the lack of significant correlations. In order to overcome this problem, change scores from the first hazard handling test to the second were calculated for each participant. None of these change scores differed significantly from zero, although there was a medium effect for bends suggesting that response rates to these hazards increased somewhat in the second implementation of the test. This may be an indication of a practice effect emerging for bends, with participants changing their behaviour more often in relation to bends in the second test. For all other hazards it would appear that no change in individual behaviour had occurred. Overall, these results suggest that the hazard handling test shows good test-retest reliability.

Finally, a comparison of responses to hazard variables and control variables (i.e. events which initially looked the same as the hazards but did not move or require the driver to change their behaviour in any way) shows that participants responded to significantly more hazardous variables than non-hazardous ones. This provides evidence that the criterion for a response (a change of two standard deviations from mean steering or pedal behaviour) was sufficiently stringent to capture actual hazard responses. Experienced drivers were better than novice drivers at discriminating between hazardous and non-hazardous events. However, the high response rate of both groups to non-hazardous events (over 49%) is worrying as it suggests that the criteria for a hazard response may not be stringent enough and some false alarms may have been mistakenly represented as responses.

6.4.2 Transfer of Learning

As outlined in Section 6.1.3, the Speed and Distance training was defined as being far from the transfer test on all three dimensions of content, with the training requiring participants to apply the general principles of speed and distance evaluation acquired through training to more specific situations (e.g. distance to pedestrians) arising in the transfer test. In terms of circumstances, the training would have required far transfer of learning on the physical context and knowledge domains, with the transfer test requiring participants to put knowledge gained in a featureless environment to use in the more ecologically valid driving environment of the hazard handling test. The results provide little evidence that any transfer of learning from the speed and distance training took place. There was no change in overall response times or response rates to hazardous events between the pre-training and post-training hazard tests and a detailed analysis of change scores in relation to individual hazards showed that these did not differ significantly from zero, or from control group scores. Therefore, it cannot be said that either near or far transfer of learning occurred for the Speed and Distance training group.

The Situation Awareness training was closer in content to the hazard handling test than the Speed and Distance training. It required specific knowledge on the dimensions of learned skill, but a more general performance change that was different from what was taught in training. Participants were presented with traffic lights, and pedestrians or car emerging events which were similar, although not exactly the same as the events presented in the hazard handling test. Similar to the speed and distance training, the dimension of memory demands once again required participants to recognise, select, and implement actions based on a memory of knowledge gained through training, although no hints of this overlap were explicitly provided. The hazard handling test required near transfer on the temporal context, functional context, social context, modality, and situational demand dimensions of the circumstances domain. However, far transfer was required on the knowledge domain as the manoeuvres taught in training were different from those required in the transfer context, although the physical context was similar. Thus it might have been expected that Situation Awareness training was more likely to result in transfer of learning than Speed and Distance training as the testing scenario was closer on more dimensions to the training scenario. However, the results provide little evidence that any transfer of learning occurred for this group. There were no significant changes in response rates or response times to hazards in the pre-training and post-training tests. An analysis of change scores, which take into account individual variability in response patterns, found no significant differences between the Situation Awareness training group and the Control group.

Finally, there did not appear to be any experience-related differences in the transfer of learning to the hazard handling tests. Experienced drivers in the two training groups responded more quickly to hazardous events than novice drivers. Unexpectedly, this result did not emerge for the control group, although it may be linked to the small sample size used in this analysis. There were no differences between the two experience groups in terms of any changes occurring between the pre- and post-training tests.

6.4.3 Summary and Conclusions

The specific hypotheses being addressed in this study were as follows:

- Hypothesis 1: Training in basic vehicle control and perception elements i.e. speed and distance, will lead to transfer of learning resulting in improved performance in dimensions of a hazard handling test.
- Hypothesis 2: Training in higher order driving skills i.e. situation awareness will lead to transfer of learning resulting in improved performance in dimensions of a hazard handling test.
- Hypothesis 3: Hazard handling performance after training will be different for drivers in the speed and distance group than in the situation awareness group, as the two groups differ in terms of how ‘near’ or ‘far’ they are from the testing context in terms of Groeger and Bank’s (2007) taxonomy.
- Hypothesis 4: Members of the control group will not show any change in hazard handling behaviour between their first and second times taking the test.

The results provide very little evidence that any transfer of learning took place, thus the null hypothesis cannot be rejected for Hypotheses 1, 2 or 3. Participants’ performance in the hazard handling test did not improve after either type of training, and any change scores arising were very similar to those of the control group. There were also no differences in the performance patterns of novice and experienced drivers as a result of training. Support was provided, however, for Hypothesis 4, as there was no significant change in the response pattern of drivers in the control group between Time One and Time Two. Finally, the pattern of results emerging from this study is similar to the previous implementation of the hazard handling test discussed in Chapter 3, providing evidence that the novice-experience difference in response time is a reliable effect.

7 Chapter 7: Final Discussion and Conclusions

This doctoral thesis examined various methods of measuring the process of responding to hazardous events in the driving environment, along with methods of improving drivers' perception skills through training. This discussion aims to summarise the methods and findings of the measurement and training studies; describe the contribution of these findings to knowledge; discuss the limitations and strengths of the current approach; and explain how these findings relate to the Cognitive Account of Driving proposed by Groeger (2000).

7.1 Hazard Perception and Transfer Overview

The first chapter of this thesis provided a synopsis of the literature surrounding young, inexperienced driver accidents. Hazard perception has been identified as one of the main sources of any skill gap between novice (less safe) and experienced (safer) drivers, since it is the only domain-specific skill that has been found to correlate with drivers' accident records across a number of studies (Horswill & McKenna, 2004). Although no one definition of hazard perception exists it is generally described as involving "appreciation, anticipation, and reading the road" (Grayson & Sexton, 2002, p. 4). It is often measured by presenting participants with a video of a driving situation and asking them to make a button press response to any event which could potentially be dangerous. Studies using this methodology have found that experienced drivers respond more quickly than novices to hazards presented (e.g. Smith et al., 2009; Wallis & Horswill, 2007), although the definition of what constitutes a novice driver and what constitutes an experienced driver differs across studies. However, studies have rarely examined what happens after a hazard is initially detected. The Cognitive Account of Driving developed by Groeger (2000) tackles this issue by presenting a model of risk response which focuses on both the detection of a hazard, and on what happens next (see Section 1.3.3). This model was used to frame the development of the first two studies included in this thesis (Chapters 2 and 3), the results of which are discussed further in Section 7.2.

Chapter 1 also provided an introduction to the concept of transfer of learning, or the application of knowledge or skill acquired in one situation to a new, novel task (Pennington et al., 1995). This concept is particularly relevant to driving, since it would be impossible to provide learner drivers with experience of every situation which could arise outside of training. A number of studies have attempted to design training regimes which lead to transfer of learning to hazard perception tests, with varying degrees of success. These training techniques have included commentary training, where participants either create or listen to a verbal commentary on any hazardous situations which occur in a driving scenario (Crundall et al., 2010; Wallis & Horswill, 2007); and anticipation training, which focuses on the generation of predictions about the likely outcomes of potential road hazards (Chapman et al., 2002; Fisher et al., 2006; McKenna & Crick, 1997). It would appear that these types of training lead to some transfer of learning in terms of improving the hazard perception performance and eye-movement patterns of novice drivers. However, there is limited evidence of any changes in hazard handling behaviour. In addition, little attempt has been made to provide an explanation for the mechanisms by which any transfer of learning might have occurred, although it would appear that both regimes focus on the verbalising of learning. In Chapters 4 and 5 of this thesis, two different training regimes were developed. One of these focused on providing intense training in the molar elements of perception while driving, specifically the judgements of speed and distance. The second training regime focused on the development of higher-order perception skills through a focus on situation awareness skills. The findings of these studies are discussed further in Sections 7.3.1 and 7.3.2. Chapter 6 provided an evaluation of the level of transfer of learning which occurred from these studies to performance on the simulator based hazard handling test (see Section 7.3.3).

7.2 Summary of Hazard Detection and Hazard Handling Results

The focus in the first and second chapters of the thesis was on the development of two measures of hazard responding. The measurement techniques were based on Groeger's (2000) Cognitive Account of Driving. This model separates the process of responding to a driving risk into four main steps; hazard detection, threat appraisal, action selection and implementation. The first stage is a process that detects changes which would imply some interruption/threat to the currently active goals. The second is a process that appraises the threat of these changes. Thirdly the driver must select and construct the most appropriate form of action to deal with the particular set of circumstances (in some cases this may be no action); and finally, the driver must implement any changes in current activity necessary.

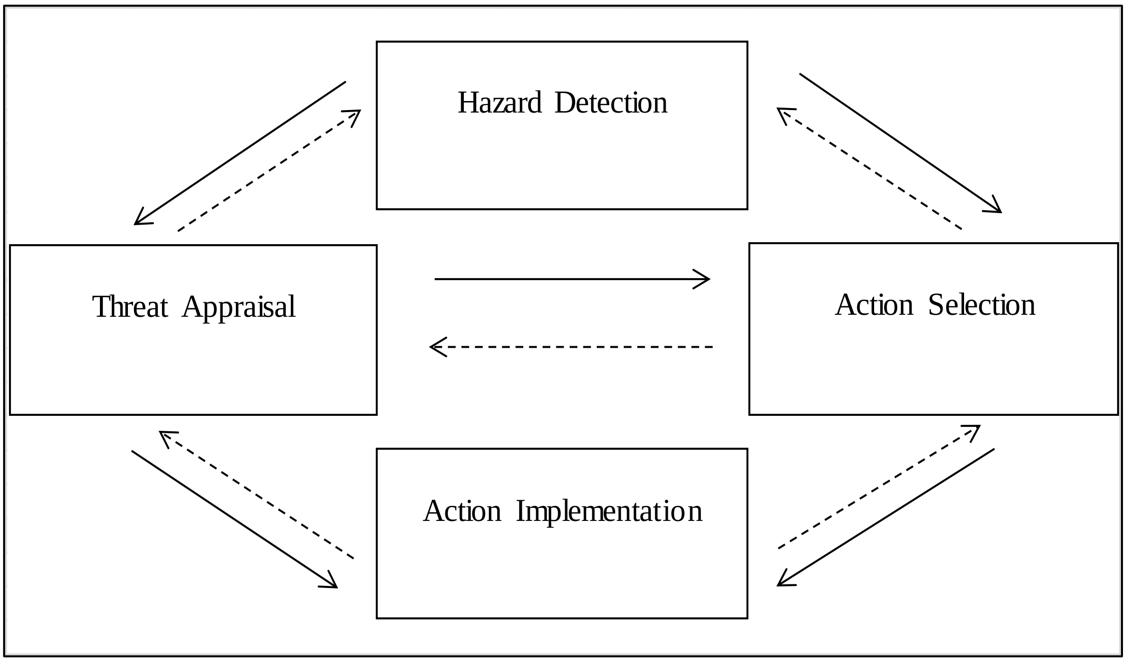


Figure 51: Cognitive Account of Driving (the bold arrows represent hypothetical forward links and the dashed arrows represent hypothetical feedback links).

It is argued that traditional button-press response methods of measuring hazard perception (see Chapman & Underwood, 1998; Sagberg & Bjørnskau, 2006; Wallis & Horswill, 2007) focus on the first step of hazard detection. In this research, this process was measured in an immersive driving simulator environment, enabling a more realistic driving experience than computer-based tests. Chapter 2 provides an outline of the results emerging when novice and experienced drivers performance on this test was compared. Results indicated that the initial version of this test failed to discriminate successfully between novice and experienced drivers in terms of either response time or response rate to hazardous events. However, there were a number of design issues with the initial version of the test and a new, more tightly controlled version outlined in Chapter 3 succeeded in discriminating between the two groups in terms of their response times to particular hazards. Experienced drivers responded more quickly than novice drivers to pedestrians who walked onto the road ahead of the driver, and to cars which pulled out perpendicularly ahead of the driver. For traffic light events in this test, experienced drivers were faster than novice drivers in making a lever press response when amber onset occurred in the safe stopping zone.

These results highlight the importance of taking the characteristics of particular hazards into account when evaluating hazard responses, as not all hazards were perceived as containing equal levels of threat.

Both the first (Chapter 2) and second (Chapter 3) versions of the hazard handling tests successfully discriminated between the two experience groups, even when the effects of age were taken into consideration. Pedestrian events appeared to be the strongest discriminator, with experienced drivers responding more quickly to these types of hazard than novice drivers in both versions of the test. In the second version of the test, experienced drivers also responded more quickly to cars pulling out and entering the traffic flow ahead (merging traffic events). The importance of these results will be elaborated on further in Section 7.4.

Previous research has shown that the biggest difference between accident involved and non-accident involved drivers occurred at the threat appraisal stage of the Cognitive Account of Driving (Grayson et al., 2003). This stage predicts that hazard responses will depend on the level of threat perceived, and that drivers will base their decision of what action to take, if any, on how much risk they feel at a given moment. Amongst other things, this will depend on the characteristics of the environment at that given moment, and how early a potential risk is detected. In order to establish whether characteristics of the environment had any effect on threat appraisal, and through this hazard detection and hazard handling, the studies outlined in Chapters 2 and 3 provided an in-depth investigation of individual hazard types, particularly pedestrians and traffic lights. Results indicated that hazards which involved interactions with other road users i.e. pedestrians and other vehicles, were more likely to discriminate between novice and experienced drivers than hazards involving interactions with fixed elements of the environment i.e. traffic lights and bends. These differences emerged more consistently in the hazard handling test than in the hazard detection test. In particular, experienced drivers changed their behaviour around a pedestrian hazard more quickly than novice drivers in both versions of the hazard handling test.

Chapter 3 built on the findings of the two hazard tests by examining their relationship to a measure of participants' knowledge of driving theory. Anderson

(1982) distinguishes between declarative knowledge, or explicit factual information about a domain; and procedural knowledge, or implicit, skill based knowledge. Driver theory tests are included in driver testing processes in many countries including Ireland. These tests assess the level of declarative knowledge potential drivers have about the rules of driving. However, although the tests include questions about hazardous elements in the environment, there has been little effort to determine whether or not the knowledge required for these types of tests is linked to a driver's ability to perceive and respond to hazards. Results in Chapter 3 indicated that for novice drivers, Driving Theory Test scores had a strong relationship with response rates in the hazard detection test. This suggests that both tests are tapping into a similar knowledge base. There were no relationships between novice drivers response time or response rates on the hazard detection and hazard handling tests, indicating that the two tests are measuring different aspects of driver behaviour. However, for experienced drivers there was a strong relationship between response rates in the hazard detection and hazard handling tests. Overall, these results suggest that for novice drivers, the skills involved in actually selecting and implementing a response while driving are not related to the skills involved in identifying hazardous events in a more passive hazard detection test. The implications of this will be discussed in Section 7.4.

7.3 Summary of Driver Training Studies

7.3.1 Speed and Distance

In Chapter 4, the development and implementation of a training regime designed to heighten drivers understanding of the most basic processes of driving perception was discussed. The focus in this training programme was on developing drivers' ability to judge speed and distance while driving. As these elements underlie the process of responding to all hazardous events which occur while driving, it could be assumed that improved skill in evaluating speed and distance would lead to improvements in the ability to evaluate the hazardousness of a situation. Previous research has shown that drivers are quite poor at judging their absolute speed, and tend to under-estimate how fast they are travelling, while over-adjusting when asked to make any changes to their speed (Conchillo et al., 2006; Groeger et al., 1999; Recarte & Nunes, 1996). There has been very little research into drivers ability to perceive distances while driving, and in many of these studies distances estimations are confounded with memory, as the object marking the target distance disappears before the driver makes any estimations (e.g. Baumberger et al., 2005). From the limited results available, it would appear that drivers are poor at making absolute evaluations of distance.

The training developed in Chapter 4 focused on improving drivers' ability to estimate and produce different speeds and distances in a featureless simulated driving environment. Drivers received summary feedback at the end of each speed training session, and at the end of each distance training session. The results provide us with a deeper understanding of the manner in which drivers perceive speed and distance while driving. Unlike previous studies, participants in this study were actually inclined to over-estimate their speed by approximately 6%. This may be a result of the lack of visual cues provided in this study which may have led to drivers' perceiving their speed differently. Participants were inclined to under-adjust when asked to change their speed, but this varied according to the target speed adjustment, previous speed, and previous acceleration/deceleration, indicating that judgements of speed are based on some relative evaluation of current performance compared to previous performance. The training programme was not successful in improving drivers' ability to make accurate estimations of their travelling speed. Although feedback led to a significant improvement in speed adjustments on the first day of training this effect had disappeared by the last day, suggesting that the initial feedback led people to develop quite consistent internal measures of their own speed across days. There was no overall effect of training day on speed production accuracy, but participants' ability to adjust their speed from an initial speed of 45kph did improve between day one and day four. Overall, the results suggest that drivers are quite poor at making judgements about their travelling speed, and this does not appear to improve after training, at least using the methods developed for this study.

The results regarding distance evaluation provide some insight into the manner in which drivers perceive and produce distances while driving. It was found that participants tended to under-estimate distances, and novice drivers seemed to be more susceptible to this misevaluation than experienced drivers. A large effect size suggests that the training programme may have led to improved ability to make verbal estimations of distance, although this failed to reach significance. The results show that training led to significant improvements in the production of distances, particularly shorter distances, with participants making smaller errors on the last day of training than the first. Feedback on performance also appeared to have a greater impact on distance productions on the first day of training than on the last.

Taken together the results of the Speed and Distance training provide us with greater confirmation that drivers' judgements of these basic elements of driving are based on some relative evaluation of performance, rather than absolute speed and distance values. It would appear that distance judgements can be improved using the training regime designed in this research. However, drivers' ability to estimate or produce speeds appears to be more difficult to improve. The impact of this training on hazard perception performance will be discussed further in Section 7.3.3.

7.3.2 Situation Awareness

Chapter 5 focused on the development of higher-order driving perception skills through the implementation of a Situation Awareness (SA) training programme. SA is defined as "the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future" (Endsley, 1995a, p. 36). It has previously been closely linked to hazard perception ability, with some authors claiming that the concepts are equivalent (Horswill & McKenna, 2004; McGowan & Banbury, 2004). The training designed for this thesis focused on improving drivers perception and comprehension skills through the use of the SAGAT technique (Endsley, 1995b), a method which involves pausing a simulation and asking relevant questions about elements of the environment and what they mean. Projection skills were measured using behaviour-based tasks, which required drivers to judge the movements of other road users (either pedestrians or cars emerging i.e. moving perpendicular to the road), or to judge the appropriateness of their own behaviour in relation to elements of the environment (traffic lights with different amber onset times). Participants received summary feedback on their performance on each of the tasks at the end of each training session.

Results indicated that drivers made significant improvements across aspects of all three elements of SA. They responded correctly to more questions about elements of the environment on day four of training than on day one. Novice drivers' ability to identify potentially hazardous elements of the environment (comprehension) improved to a level equivalent to that of experienced drivers by day four of training. Participants' ability to judge the movement times of pedestrians improved between day one and day four, as did their ability to judge the movement of car emerging events. There were no changes across days in drivers' ability to make accurate decisions at amber onset at traffic lights. Drivers showed that they were quite accurate in judging how much to decelerate or accelerate on the first day of training, suggesting that this is an aspect of driving which drivers pick up on relatively quickly. The results of this study provide support for the use of a mixed methodology in measuring SA, as the results provided two objective measures of drivers' ability. The results also show that drivers SA ability can be improved through training. This is positive in terms of improving driver safety, as failures related to poor SA have been identified as potential causal factors in road traffic accidents (Salmon et al., 2012).

7.3.3 Transfer of Learning

The issue of how new responses are generated when individuals are confronted by novel stimulus situations or task demands is particularly relevant in driving research since safe driving depends on the transfer of what is learned during training, or wider experience, to a wider range of circumstances than could ever be encountered during training (Groeger & Banks, 2007). Chapter 6 aimed to evaluate the success of the two training regimes outlined in Chapters 4 and 5 in promoting the transfer of learning to the hazard handling test developed in Chapters 2 and 3. In order to get a greater understanding of where 'near' and 'far' transfer of learning might be expected to take place, the two training regimes were classified using the taxonomy of transfer developed by Groeger and Banks (2007).

The results provide little evidence that any transfer of learning occurred from either training regime to the hazard handling test. Participants' response rates and response times did not differ significantly between the pre- and post-training tests. In addition, there were no differences in the change scores of training and control groups. Previous transfer literature has argued that there is no evidence that transfer of learning can occur in the absence of identical elements between the learning and testing contexts (e.g. Singley & Anderson, 1989). However, Groeger (2000) argues that it is more likely that some form of verbal mediation is required for trainees to transfer learning. This idea is supported by the driving studies which have found evidence for transfer (albeit only across short time-scales), as all of the learning contexts emphasized the verbal encoding of information (e.g. Crundall et al., 2010; Fisher et al., 2006; McKenna et al., 2006). Nokes (2009) comparison of analogical transfer, knowledge compilation, and constraints training provides further evidence for this idea, but also shows the time costs associated with verbal processing of information. The current study aimed to provide training which would not require this high level of verbal encoding, as it is unlikely drivers will have time for such processing of knowledge when presented with hazardous events. However, the results of this study suggest that transfer of learning does not occur in the absence of this verbal mediation, at least for the type of training considered in this thesis. This suggests that although deep training in distance perception, and SA skills may lead to improvement in those specific areas of driving, this is not sufficient to improve overall hazard handling skill. These results highlight the difficulties faced in developing driver training regimes which will encourage transfer of learning to new situations, and thus increase novice drivers' safety levels. Taken with the fact that many previous driver training studies have failed to find long-term transfer effects (e.g. Crundall et al., 2010), it may that short-term, intensive training regimes do not promote hazard perception and hazard handling skill. Graduated licensing regimes may provide more benefits through restricting novice drivers' exposure to hazards until they have had time to gain sufficient practice in the motor aspects of driving, although it could be argued that these regimes also fail to focus on the specific development of hazard perception (Mayhew, 2007).

A final aim of Chapter 7 was to evaluate the replication of the hazard handling test. Results for the control group, who completed two versions of the test with no training in between, show that similar patterns of results emerged in both versions of the hazard handling tests, and there was no significant change in response rates or response times in the first and second test implementation. There were no relationships between overall response times and response rates in the first and second implementations of the test. However, when response patterns to individual stimuli were compared between the first and second implementations of the test, strong correlations emerged. This indicates that the stimuli were providing the same measurement at both time-points. Overall, the results suggest that the novice-experienced differences emerging in the earlier versions of the hazard handling test can be replicated.

7.4 Contribution to Knowledge

The studies outlined in this thesis contribute to knowledge by providing a number of new insights into the understanding of hazard perception in a driving context. These studies are the first to provide an interactive, immersive assessment of both hazard detection and hazard handling skill.

Although previous studies had found an experience-related difference in response times to hazards presented in video format (e.g. Horswill & McKenna, 2004; Quimby & Watts, 1981; Smith et al., 2009; Wallis & Horswill, 2007), there was very little understanding of why this difference emerged. Using Groeger's (2000) Cognitive Account of Driving, the studies outlined in Chapters 2 and 3 of this thesis unpack this relationship thoroughly by separating out the processes of hazard detection and hazard handling. This enabled a deeper understanding of what happens for both novice and experienced drivers after a hazard is initially detected. The results obtained in these studies suggest that both groups have similar ability to detect hazardous events in the environment. However, experienced drivers are consistently faster at responding to these events, particularly when driving themselves. This finding suggests that experience-related differences in hazard perception emerge in the processing of hazard responses, rather than in the detection of hazardous events.

The process of skill acquisition is commonly broken into the stages of declarative knowledge and procedural knowledge (Anderson, 1982). By comparing drivers' performance in a Driving Theory Test, a hazard detection test, and a hazard handling test, the study outlined in Chapter 3 provides unique insights into the manner in which novice drivers proceduralise knowledge in relation to hazard perception skill. No significant relationships emerged, for either novice or experienced drivers, between response times in the hazard handling and hazard detection conditions. This suggests that what is being measured in these tests is not the same. It would appear that for novice drivers, their ability to detect hazardous events in a simple lever-press test is closely linked to their ability to answer questions about their driving knowledge (as measured through the Driving Theory Test). This explicit knowledge of driving does not appear to have been proceduralised, as exhibited by the lack of a relationship between performance on the hazard detection and hazard handling tests. Thus, it would appear that the motor skills involved in selecting and implementing a response while driving, are not strongly related to the skills involved in identifying the same hazardous events in a more passive environment. Underwood (2007) suggested that for novice drivers, the driving task, including steering, changing gears and speed control has not been automated enough to free up the attentional capacities required to enable effective road situation awareness. The results obtained in this thesis provide support for that idea. It seems that novice drivers, relying on declarative information can determine what events are potentially hazardous when watching a driving video. However, they do not appear to have sufficient mental resources to process this declarative information in the same manner when actually driving. There is a stronger link between the hazard detection and hazard handling environments for experienced drivers, suggesting that they have a greater ability to identify hazardous elements of the environment, regardless of whether or not they are in control of the vehicle.

Although Groeger's (2000) model suggests that the process of responding to a hazard in the hazard detection test should involve less mental processing than in the hazard handling tests, participants actually reacted more quickly to hazards in the hazard handling tests. This suggests that the speed of response to any hazardous event depends on how practiced a particular response is. Drivers are practiced in changing their steering and pedal behaviour in relation to elements of the driving environment, and appear to have proceduralised this process. However, the process of pulling a lever to sound a horn may not be as automatic and, as a result the implementation of the response may take longer. Therefore, button-press measures of hazard perception may not be providing an accurate measure of how quickly drivers can respond to hazardous events. This provides an explanation as to why a more reliable experience related difference was found in the hazard handling condition (significant experience effects emerged in both Chapter 2 and Chapter 3), as experienced drivers have gained the necessary procedural knowledge of driving to change their behaviour almost automatically upon detection of a hazard, whereas novice drivers have not.

Groeger's (2000) model also emphasised the importance of threat appraisal in the hazard responding process. With a few exceptions (Crundall et al., 2012; Scialfa et al., 2012), previous studies of hazard perception have failed to examine what it is about specific hazards that makes them more/less threatening. The studies outlined in Chapters 2 and 3 addressed this gap, by comparing the discrimination power of different types of hazardous events. Results indicated that hazards which involved interactions with other road users i.e. pedestrians and other vehicles, were more likely to discriminate between novice and experienced drivers than hazards involving interactions with fixed elements of the environment i.e. traffic lights and bends. These differences emerged more consistently in the hazard handling test than in the hazard detection test. In particular, experienced drivers changed their behaviour around a pedestrian hazard more quickly than novice drivers in both versions of the hazard handling test. Thus, it would appear that novice drivers have a great need to proceduralise knowledge in relation to appropriate measures for dealing with pedestrian hazards. This is something which should be incorporated into future driver training.

7.5 Limitations & Ideas for Future Research

While the studies outlined in this thesis produced a number of interesting findings, there were some limitations which must be discussed. The main methodological issues concern the measurement of "responses" in the hazard handling test, the simulator methodology, and the size of the samples in the training studies.

7.5.1 Measuring Responses

For the purposes of the hazard handling studies outlined in this thesis a hazard "response" was taken to be any change in the steering, accelerator, or brake pedals of two standard deviations or more from the mean steering/pedal positions for a five second period prior to the trigger of a hazard. The measurement window for calculating the mean steering/pedal responses was static and thus may not be providing the most accurate measure of average participant behaviour. In addition, there was a very high number of responses to hazards across all three versions of the hazard handling test, leading to a concern that the response criterion was not strict enough and false responses may have been included. In order to tackle this issue control variables were included in the versions of the hazard handling test used in Chapters 3 and 6. A comparison of responses to control variables and hazardous variables showed that participants responded to significantly more hazard variables than controls, and responses to the hazards were measurably faster for participants in Chapter 3. However, participants still responded to over 40% to control variables in both versions of the hazard handling test, suggesting that the response criterion may need to be tightened more. Alternatively, it would be interesting to explore the effect of having a moving measure of mean behaviour so that steering/pedal positions were being compared at all times to the moments directly preceding any action, rather than the moments prior to hazard onset.

A second measurement concern surrounds the evaluation of response times to bends. Unlike the other hazards included in this research, there was no ‘trigger’ point for bends in the road. Responses were measured from the point at which the curvature of the road began. However, it is possible that safe drivers would begin to change their behaviour much earlier than this. It is also possible that for bends, an early and gentle change in behaviour may be a more appropriate response than the more extreme change captured under the two standard deviations criterion. Unfortunately, some of the bends in the first version of the test failed to trigger properly, leading to a lack of simulator output for certain bends. In addition, there was a very low response rate to bends in the second version of the hazard detection study. Thus, it was outside the scope of this thesis to examine the issue of bends as hazards more thoroughly. However, as many young driver accidents occur on bends (Clarke et al., 2006), an in-depth analysis of bends may provide a deeper understanding of how and when safe responses to bends are made.

7.5.2 Simulator Methodology

One of the strengths of this research over previous studies in hazard perception was the use of a fully immersive simulated environment. However, although this technology provided a more ecologically valid testing environment than traditional button-press tests of hazard perception, there is still some concern over the absolute and relative validity of simulator results. Absolute validity refers to the numerical correspondence between behaviour in the driving simulator and in the real world. Relative validity refers to the correspondence between effects of different variations in the driving situation (Bella, 2008). Törnros (1998) claims that a driving simulator must have satisfactory relative validity in order to draw research conclusions.

However, he states that absolute validity is not a necessary requirement, as research questions generally deal with matters relating to the pattern of effects of independent variables rather than the actual numerical values. Although the relative validity of UCC's driving simulator has not been tested, research to do so is currently underway, with initial results seeming positive.

One concern for the current research relates to the Speed and Distance training outlined in Chapter 4. In this study the pattern of results for both the estimation and production of speed was in the opposite direction from on-road research (e.g. Conchillo et al., 2006; Recarte & Nunes, 1996). However, participants were obviously consistent in their evaluations of speed in the simulated environment. It is possible that the difference in the speed evaluations may have resulted from the fact that lower speeds were used in this research than in previous research, as it is clear from both the on-road research and the present research that the travelling speed affects the accuracy of estimations (Recarte & Nunes, 1996). In addition, research has shown that the level of optic flow present can affect driver estimates of speed (Groeger et al., 1999; Mourant et al., 2007), and the use of a featureless environment may explain the higher estimates of participants in the current research. On a more positive note, this ability to manipulate features of the environment allows the development of a deeper understanding of how drivers perceive their own movement (as measured in Chapter 4), and that of other road users (see Chapter 5). In addition the use of a driving simulator allows the presentation of situations which would be too dangerous to implement in on-road driving, and thus provides an advantage in terms of understanding hazard responses.

7.5.3 Sample Sizes

A further limitation of the research was the small sample sizes of the training studies. Due to time constraints it was only possible to collect data from twenty participants for each of the training studies (in previous driver training studies the number of participants had ranged from 12 trainees in McKenna and Crick's (1997) study to 72 trainees in Chapman et al.'s (2002) study). This led to a number of cases where effect sizes suggested that a meaningful change in behaviour had occurred but there was insufficient power to draw definite conclusions. In particular, the design of the Situation Awareness training meant that only ten participants completed the pedestrian and car emerging aspects of the projection training. However, the fact that significant changes in behaviour emerged even with these small samples provides strong support for the claim that the training was successful. It would be interesting to establish whether or not a larger sample size would allow stronger conclusions to be drawn for the distance estimation training where the difference between accuracy on the first and last day of training had a medium effect size, despite being non-significant.

7.6 Conclusions

The research presented in this thesis expands on the previous literature in hazard perception, by comparing the responses made by drivers in a discrete-response hazard detection test to the handling responses made to the same hazards while actually driving. Previous research has generally been interpreted on a post-hoc basis, thus an in-depth theoretical understanding of how safe drivers identify and respond to hazards has not been possible (Crundall et al., 2012). The research included in this thesis has been based on a theoretical model called the Cognitive Account of Driving (Grayson et al., 2003; Groeger, 2000). This has enabled an evaluation of where novice and experienced drivers differ in terms of their hazard responses, but also provides an explanation as to why these differences may emerge. Across all versions of the hazard detection and hazard handling tests, novice and experienced drivers responded to a similar number of hazards, suggesting that both groups are capable of identifying the hazardous elements of the driving environment. However, experienced drivers made earlier responses to hazards in all versions of the hazard handling test, suggesting that these drivers are more quickly able to evaluate the threat contained in potential hazards, and select and implement a response. The processes of hazard detection and hazard handling do not appear to be related for novice drivers, suggesting they have yet to gain the skill-sets to deal with the perception elements of driving while also concentrating on motor control of the vehicle. The analysis of individual hazard situations shows the importance of taking into account the level of threat perceived in any hazardous event, and this will depend on the individual characteristics of the hazard e.g. where the driver is located when amber onset at a traffic light occurs.

The training studies have provided evidence that elements of drivers perception of their own (Speed and Distance) and other drivers movements (Situation Awareness) can be improved using simulator training. Speed and distance judgements underlie all aspects of hazard responding, and situation awareness has sometimes been equated with hazard perception skill. However, although these elements of driver perception can be improved through training, the improved skills do not appear to lead to any transfer of learning when faced with new situations in the hazard handling test. This finding highlights the importance of evaluating all training regimes in terms of how well they promote transfer of learning to new environments. It is also important to define exactly when and where any transfer takes place. This research shows that it is possible to change drivers' behaviour through training, but the ultimate challenge is to establish a way to translate this improvement into benefitting new situations. It may be that graduated licensing regimes, which restrict novice drivers' exposure to hazards until they have had time to gain sufficient practice in the motor aspects of driving, hold the key to this improvement.

8 References

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Appendix A: Simulator Sickness Questionnaire

Subject Screening Number: __ __ __ __ **Drive status:** Pre Drive 1/Post Drive 1

Subject Initials: __ __ __ **Day:** __ __ **Date:** dd **/** mm **/ 2012**

Temperature:_ _ _ _ _ _ _

Below you will see a number of physical symptoms you might currently be feeling, please tick each symptom in terms of whether you feel to a "Severe"," Moderate", "Slight" extent, or not at all ("None"). Several of the symptoms are very similar, so please consider each item carefully in terms of ***how you feel now****.*

	SSQ Symptom	``None"	``Slight"	``Moderate"	``Severe"	Score
1	General discomfort					
2	Fatigue					
3	Headache					
4	Eyestrain					
5	Difficulty focusing					
6	Increased salivation					
7	Sweating					
8	Nausea					
9	Difficulty concentrating					
10	Fullness of head					
11	Blurred vision					
12	Dizzy (eyes open)					
13	Dizzy (eyes closed)					
14	Vertigo					
15	Stomach awareness					
16	Burping					
17	Drowsiness					
18	Faintness					
19	Stomach discomfort					
20	Muscle stiffness					

Scoring

Participants report the degree to which they experience each of the above symptoms as one of ``None", ``Slight", ``Moderate" and ``Severe". These are scored respectively as 0, 1, 2 and 3.

For the purposes of screening only items 1,3,7,8, 11, 12, 13, 17, 18, 19.

Appendix B: T-tests comparing Novice and Experienced Drivers Responses of 0.5SD, 1SD, and 2SD

Table 72: Independent samples t-test comparing 0.5SD, 1SD, and 2SD changes in behaviour of novice and experienced drivers for Chapter 2

			0.5SD: Response Rate				
	Experience Group	**N**	**M**	**SE**	**T**	**p**	**Cohen's *d***
Car Emerging	Novice	17	1.00	0.00			
	Experienced	22	1.00	0.00			
Merging Traffic	Novice	17	0.96	0.02	-0.72	0.48	0.23
	Experienced	21	0.98	0.02			
Pedestrian	Novice	17	0.70	0.03	-0.05	0.96	0.01
	Experienced	21	0.70	0.03			
Traffic Light	Novice	17	0.92	0.01	1.21	0.23	0.40
	Experienced	21	0.90	0.01			
Bends	Novice	16	1.00	0.00			
	Experienced	21	1.00	0.00			
All Hazards	Novice	17	0.92	0.01	-0.10	0.92	0.03
	Experienced	21	0.92	0.01			
			0.5SD: Response Time				
	Experience Group	**N**	**M**	**SE**	**T**	**p**	**Cohen's *d***
Car Emerging	Novice	17	0.59	0.12	1.92	0.06	0.60
	Experienced	22	0.37	0.04			
Merging Traffic	Novice	17	0.41	0.04	1.60	0.12	0.52
	Experienced	21	0.33	0.03			
Pedestrian	Novice	17	0.76	0.07	1.26	0.22	0.29
	Experienced	21	0.65	0.05			
Traffic Light	Novice	17	0.77	0.13	0.76	0.45	0.24
	Experienced	21	0.67	0.07			
Bends	Novice	16	0.22	0.03	0.13	0.90	0.04
	Experienced	21	0.22	0.02			
All Hazards	Novice	17	0.56	0.04	2.54	0.02	0.80
	Experienced	21	0.45	0.02			

	1SD: Response Rate						
	Experience Group	**N**	**M**	**SE**	**t**	**p**	**Cohen's *d***
Car Emerging	Novice	17	0.97	0.03	-0.18	0.86	0.06
	Experienced	22	0.98	0.02			
Merging Traffic	Novice	17	0.94	0.03	-1.35	0.19	0.42
	Experienced	21	0.98	0.01			
Pedestrian	Novice	17	0.98	0.01	0.22	0.83	0.07
	Experienced	21	0.98	0.01			
Traffic Light	Novice	17	0.87	0.03	0.32	0.75	0.10
	Experienced	21	0.86	0.02			
Bends	Novice	18	0.98	0.01	-1.14	0.26	0.35
	Experienced	22	0.99	0.01			
All Hazards	Novice	17	0.95	0.01	-1.16	0.25	0.37
	Experienced	22	0.96	0.01			
	1SD: Response Time						
	Experience Group	**N**	**M**	**SE**	**t**	**p**	**Cohen's *d***
Car Emerging	Novice	17	0.58	0.10	1.84	0.07	0.57
	Experienced	22	0.40	0.04			
Merging Traffic	Novice	17	0.48	0.05	1.66	0.11	0.53
	Experienced	21	0.38	0.03			
Pedestrian	Novice	17	0.90	0.10	1.72	0.10	0.54
	Experienced	21	0.72	0.05			
Traffic Light	Novice	17	0.71	0.07	0.19	0.85	0.06
	Experienced	21	0.70	0.05			
Bends	Novice	15	0.06	0.01	-0.36	0.73	0.12
	Experienced	19	0.06	0.01			
All Hazards	Novice	17	0.56	0.04	2.17	0.04	0.69
	Experienced	21	0.47	0.03			

	2SD: Response Rate						
	Experience Group	**N**	**M**	**SE**	**t**	**p**	**Cohen's *d***
Car Emerging	Novice	17	0.94	0.04	-0.31	0.76	0.09
	Experienced	22	0.96	0.03			
Merging Traffic	Novice	17	0.93	0.03	-1.71	0.10	0.54
	Experienced	21	0.98	0.01			
Pedestrian	Novice	17	0.97	0.02	-0.62	0.54	0.20
	Experienced	21	0.98	0.01			
Traffic Light	Novice	17	0.77	0.03	-0.19	0.85	0.06
	Experienced	21	0.78	0.02			
Bends	Novice	17	0.97	0.01	-0.12	0.91	0.04
	Experienced	21	0.97	0.01			
All Hazards	Novice	17	0.91	0.01	-1.56	0.13	0.49
	Experienced	23	0.94	0.01			

	2SD: Response Time						
	Experience Group	**N**	**M**	**SE**	**t**	**p**	**Cohen's *d***
Car Emerging	Novice	17	0.69	0.14	1.85	0.07	0.55
	Experienced	22	0.46	0.04			
Merging Traffic	Novice	17	0.58	0.07	1.90	0.07	0.60
	Experienced	21	0.44	0.03			
Pedestrian	Novice	17	1.07	0.10	1.75	0.09	0.56
	Experienced	21	0.87	0.06			
Traffic Light	Novice	17	0.80	0.07	0.32	0.75	0.10
	Experienced	21	0.77	0.06			
Bends	Novice	17	0.06	0.01	-0.34	0.73	0.11
	Experienced	21	0.07	0.01			
All Hazards	Novice	17	0.64	0.05	2.43	0.02	0.74
	Experienced	23	0.52	0.02			

Appendix C: Demographic Questionnaire

1. General Background Questionnaire (1)

PERSONAL INFORMATION

1. Contact Information

First Name

Surname

Email

2. Demographic Information

	Day	Month	Year
Date of Birth			

3. Gender

- ◯ Male
- ◯ Female

4. Which best describes your Ethnic Group (please mark closest category)

- ◯ Caucasian
- ◯ Black (including Caribbean, African, Other)
- ◯ Asian (including Indian, Pakistani, Bangladeshi, Chinese, Other)
- ◯ Other

2. General Background Questionnaire (2)

EDUCATIONAL BACKGROUND

5. Have you completed your Leaving Certificate?

- ◯ Yes
- ◯ No

6. If you have completed your Leaving Certificate, please answer the following:

Please select the following points range in which your results fell.

- ◯ {600}
- ◯ {500 - 599}
- ◯ {400 - 499}
- ◯ {300 - 399}
- ◯ {200 - 299}
- ◯ {100 - 199}
- ◯ {less than 100}

7. What is your most recent academic qualification?

8. Please select the country where your most recent academic qualification was obtained.

	Country
Select from the following	

3. General Background Questionnaire (3)

DRIVER LICENCE INFORMATION

9. Are you a licensed driver?

- ◯ Yes
- ◯ No

10. Do you have a driving licence that entitles you to drive in IRELAND?

- ◯ Yes
- ◯ No

11. What type of driver's licence do you hold?

- ◯ FULL Driver's Licence
- ◯ PROVISIONAL Driver's Licence

12. In which year did you recieve your driver's licence?

	Year	Month
Please select from the following:		

13. How many years driving experience do you have in total?

14. In what month and year did you start to drive?

Please enter: DD / MM / YYYY

15. In what month and year did you complete your Driving Theory Test?

Please enter: DD / MM / YYYY

4.

16. Approximately how far do you drive in an average year (answer in miles OR kilometers)?
***If you have been driving less than 1 year, give total miles/kilometers driven**

If you do not know the specific answer, please estimate and indicate that the answer is such.

Distance travelled

Please specify measurement used (miles/kilometeres).

17. How often do you drive?

- Every day
- A few days a week
- A couple of days a week
- Less often

18. Do you usually wear glasses when driving?

- Yes
- No

Appendix D: Distribution of Response Rate and Response Time Data for Chapter 3

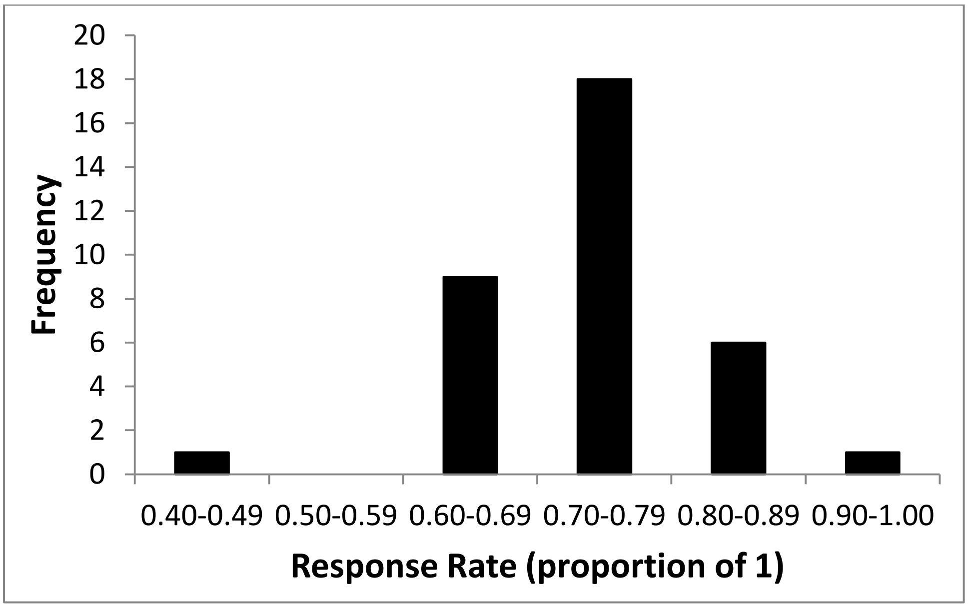

Figure 52: Distribution of Response Rate data for hazard detection test

The Kolmogorov-Smirnov statistic indicates normality (z(36)=0.75, p=0.62).

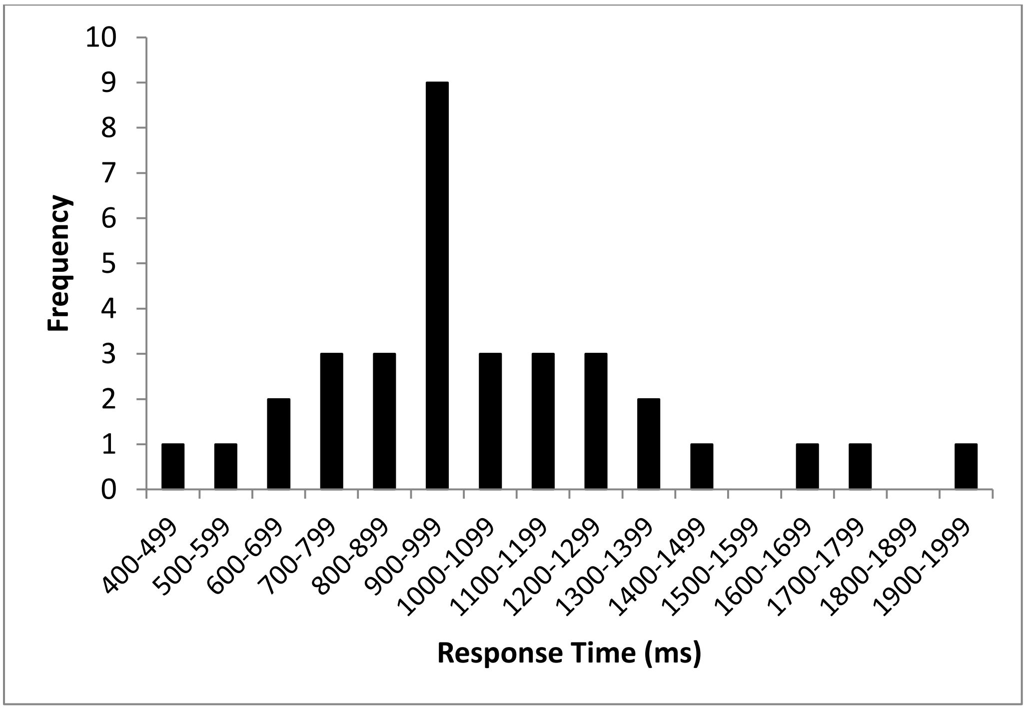

Figure 53: Distribution of Response Time data for hazard detection test

The Kolmogorov-Smirnov statistic indicates normality (z(36)=0.84, p=0.49).

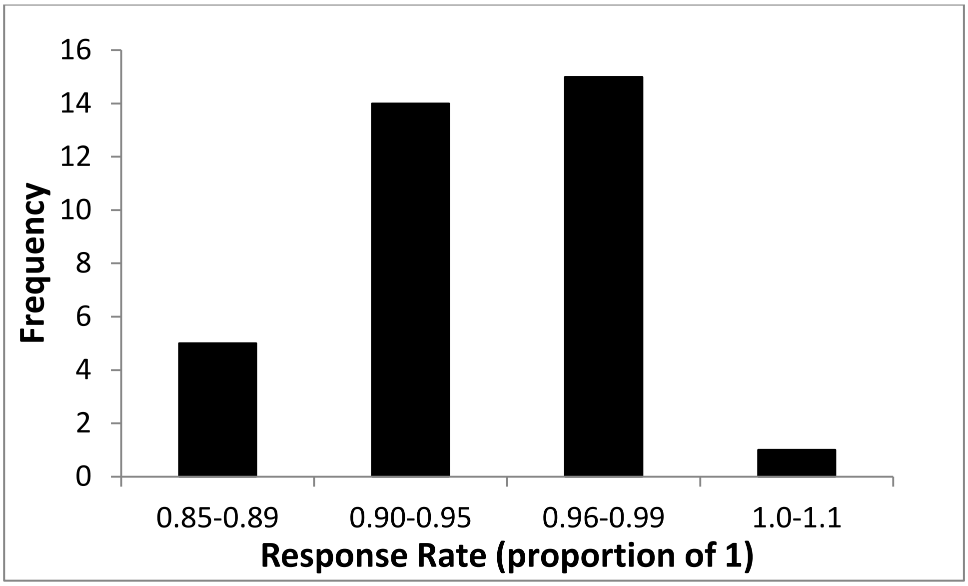

Figure 54: Distribution of Response Rate data for hazard handling test

The Kolmogorov-Smirnov statistic indicates normality ($z(36)=0.81$, $p=0.53$).

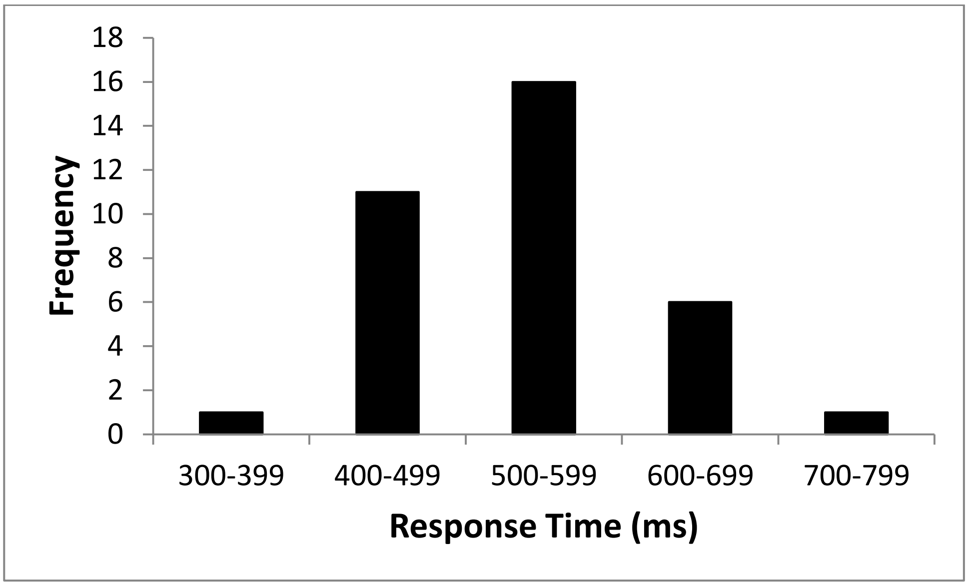

Figure 55: Distribution of Response Time data for the hazard handling test

The Kolmogorov-Smirnov statistic indicates normality ($z(36)=0.80$, $p=0.54$).

Appendix E: Situation Awareness Training – Perception & Comprehension Questions

Version 1

1st Pause:

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

2nd Pause:

How many dogs did you pass since the last time the screen went blank?
What was the vehicle ahead of you at the point at which the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

3rd Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

4th Pause

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

5th Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

Version 2

1st Pause:

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?

What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

2nd Pause:

How many dogs did you pass since the last time the screen went blank?
What was the vehicle ahead of you at the point at which the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

3rd Pause

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

4th Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

5th Pause

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

Version 3

1st Pause:

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

2nd Pause:

How many dogs did you pass since the last time the screen went blank?
What was the vehicle ahead of you at the point at which the screen went blank?

What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

3rd Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

4th Pause

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

5th Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

Version 4

1st Pause:

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

2nd Pause:

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

3rd Pause

How many dogs did you pass since the last time the screen went blank?
What was the vehicle ahead of you at the point at which the screen went blank?

What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

4th Pause

How many adult pedestrians did you pass since the last time the screen went blank?
What was the most recent vehicle you passed before the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?

5th Pause

How many child pedestrians did you pass since the last time the screen went blank?
What was the first vehicle you passed since the last time the screen went blank?
What, if anything, was in your rear-view mirror at the point at which the screen went blank?
What signposts, if any, did you pass since the last time the screen went blank?
What elements of the environment were the most hazardous, or had the potential to become hazardous, at the point at which the screen went blank?